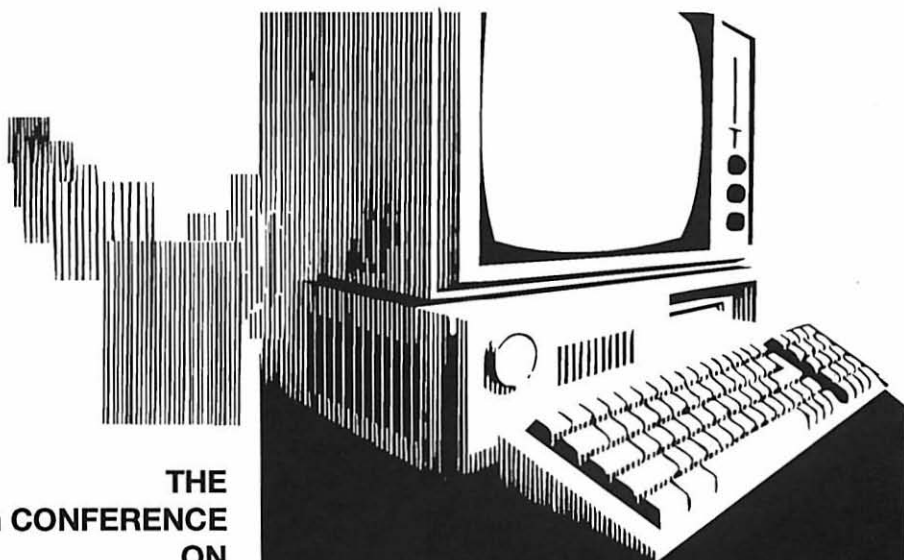




THE
12th CONFERENCE
ON
COMPUTER
APPLICATIONS
IN
RADIOLOGY
AND
8th CONFERENCE
ON
COMPUTER
ASSISTED
RADIOLOGY

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JUNE 12-15, 1994

SCAR 94

COMPUTER APPLICATIONS TO ASSIST RADIOLOGY

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FUTURE SYMPOSIA

The following meetings are already well along in the planning stages. Please mark your calendars for the following:

CAR '95 - Computer Assisted Radiology

June, 1995 - Berlin, Germany

S/CAR '96 - Symposium for Computer Assisted
Radiology

University of Colorado Health Sciences Center

June, 1996 - Denver, Colorado

Introduction

Background

The 12th Conference on Computer Applications in Radiology is one of a series of meetings which began in 1964 under the sponsorship of the American College of Radiology (ACR). These symposiums emphasize recent developments in medical imaging with particular attention to advances in computer technology that affect information systems.

Beginning with the 9th conference, which was held in Hilton Head, South Carolina, in 1988, and continuing through this current year, the symposium has been cosponsored by the ACR and the Radiology Information System Consortium (RISC), a nonprofit organization dedicated to stimulating the development of quality computer-based systems in our field.

The Society for Computer Applications in Radiology (SCAR) was formed several years ago to provide a forum for the exchange of scientific information concerning the use of computers in radiology. SCAR was formed under the umbrella of RISC. The symposium directed by SCAR has been augmented by the society's affiliation with the international organization of Computer Assisted Radiology (CAR). The CAR symposium, held every other year, is organized by Heinz U. Lemke, Ph.D., of the Technical University of Berlin. This biennial symposium has provided an outstanding forum for organizing the European leadership in the technical and clinical aspects of computer technology in the field of radiology. The present symposium represents the merger of these two previously separate series of conferences and provides a global view of an exploding opportunity in medicine.

Dr. Atsuko Heshiki is a well-recognized expert in the field and has been a major contributor to several Image Management and Communication (IMAC) conferences. She is an authority on the transmission of medical images for primary diagnosis in Japan.

S/CAR Program

The program consists of tutorials, scientific presentations, technical exhibits, poster sessions, and computer-based medical imaging demonstrations both at the Convention Center and The Bowman Gray School of Medicine, Wake Forest University.

Tutorials

Several tutorials were designed to introduce the fundamentals of computers, digital imaging, and DICOM standard. The remaining tutorials will provide overviews of a radiology department's early transitional experiences in filmless imaging and of the evolving trends in computer-based medical record and telemedicine opportunities with the use of Asynchronous Transfer Mode (ATM) networks.

Picture Archiving and Communications Systems (PACS)

Digital image management systems represent a major subset of topics addressed at the symposium. This evolving concept of electronically acquiring, transmitting, storing, and displaying radiographic images has received renewed enthusiasm from academic and industry as a result of technological advances, cost-effective potential, DICOM standard, and an overall better understanding of the opportunities associated with digital imaging. The subjects of these presentations range from clinical experiences, text and image integration, and DICOM improvements to assessment and evaluation.

Image Processing

Image processing and three-dimensional (3-D) presentation of digital images have had significant clinical impact on the overall diagnostic process. Benefits have increased with the expanded use of digital CT and MR imaging, faster computer-based processors, flexible programming languages, and an overall understanding on the part of physicians of the opportunities available. Twenty-four papers describe a wide range of image processing and 3-D techniques that support and enhance diagnosis and disease.

Expert Systems and Artificial Intelligence

Ten papers will present current experiences with expert systems and artificial intelligence and will show how their applications are influencing and assisting in the diagnostic process.

Information Systems and Teaching Applications

Computer-based radiology information systems are mature systems that have been successfully implemented for many years. The presentations concerning management systems deal with modular applications such as radiotherapy, nuclear medicine, and administrative research.

The advancement of personal computer technology has greatly expanded the teaching methods available. Several presentations also demonstrate new multimedia technologies for correlating computer-based patient files.

Computed Radiography and Research

Computed radiography, which uses photostimulable phosphor technology to produce digital radiographs, is the subject of several papers that compare digital technique to analog plain film and discuss specific clinical optimization applications. In the research section, the concept of neural networks is the focus of some promising diagnostic applications. Research is also represented in the fields of bone, MR imaging, and mammography.

Government Agency Sessions

There will be two special-interest sessions related to medical imaging supported by government agencies. The senior staff of the Medical Diagnostic Image Support (MDIS) project will present various experiences related to digital image management over the last 18 months. The Public Health Service will present recent developments in the areas of mammography, legal aspects of digital management and communication, and progress toward an international informatics standard.

Keynote Address and Focus Session: Current State of Virtual Reality

The opening keynote address by Daniel R. Masys, M.D., Director of Lister Hill National Center for Biomedical Communications, provides insight into the opportunities for health care on the Information Super Highway. The closing focus session is expected to be a thought-provoking discussion of the current experiences and future applications of virtual reality. The opening and closing sessions promise to develop a base for future technological directions in health care.

Johannes M. Boehme, Ph.D.
Associate Professor Radiology
Vice Chairman
The Bowman Gray School of Medicine

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Tutorials

Computer Basics: The Computer in the Radiologist's Office

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Computers are the backbone of CT, MRI, and digital imaging systems, and computer chips are found in all modern radiographic equipment, even the simplest portable unit. Computers are essential for radiology information management systems (RIS) and hospital information management systems (HIS). Today one is able to equip his or her office with a powerful personal computer system equivalent to the large mainframe computers of just a few years ago.

There is no one best personal computer system. Any reasonably equipped system will work well if the user takes the time to learn the system thoroughly. Computers are fun and are invaluable for many personal and professional uses. However, they require considerable investment of both money and time. In fact, monetary concerns may be less important than time concerns. No matter what is purchased, it will require some investment of time to learn the system hardware and software. Time invested up front may pay large dividends down the road. One has to be prepared to spend \$3000-5000 on a powerful system and many hours learning how to use it. It is unwise to scrimp on the initial time and money invested on a new system.

If funds permit, purchase of a Pentium chip, Power PC, or "fast" 486 or equivalent system with 300-600 megabytes of hard disk storage, 16 megabytes of random access memory (RAM), a high resolution color video card and monitor, and a laser printer is recommended. The practical uses for such a system are almost limitless and include: word processing, spreadsheet and database management, telecommunications, multimedia presentations, business applications, teleradiology, resident and medical student education, and research applications.

Becoming familiar with computer technology is not easy at first. Finding a good computer buddy, taking simple night school courses, attending computer related conferences, and reading computer articles and magazines are a good way to get started.

No matter how much one becomes involved in computer applications, it is essential to establish good habits. One of the most important good habits to

establish is the backing up of critical data files and programs. Computers are wonderful devices, but they are capable of failing at any time. In a moment's notice you can lose a year's worth of work if you have not prepared a backup system for your important data files.

Today's personal computers are "awesome." There is so much they can do for so little relative cost it is hard to imagine a radiologist's office without one. Since the 1970's, computer technology has been an important part of the radiologist's professional life, and modern imaging would be impossible without it. This same power should now be brought into the radiologist's office.

The Transition to the Filmless Imaging Department: Early Experience at the Baltimore VA Hospital

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The Baltimore VA Medical Center which opened in January 1993, installed a large scale PACS (Picture Archiving and Communications System) and has made the transition to over ninety percent soft copy (filmless) operation. Parameters required to evaluate a filmless imaging system were identified prospectively and baseline data was collected approximately five months after the hospital opened, prior to widespread use of the PAC system.

The tutorial will review the methodologies and the parameters required to evaluate a filmless imaging system, the baseline data collected from the Baltimore VA, and the early experience with soft copy interpretation in the imaging department and throughout the hospital.

Emphasis will be placed on the lessons that were learned in the process of data collection and strategies that were developed to increase the validity of the information that was obtained.

Our early experience has indicated that the installation of a PAC system and filmless operation results in a number of operational, technical, and educational tradeoffs, some of which were not anticipated. The applicability of the early data collected at the Baltimore VA Medical Center to other hospitals will be discussed.

Finally, future strategies and plans for additional data collection including comparisons with comparable hospitals and teleradiology will be discussed.

The Computer-Based Medical Record

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The information management requirements necessary for health care reform can only be met through an expansion in the availability, functionality, completeness, and integration of patient data systems. The heart of these regional information system must be the patient-centered computer-based patient record (CPR). Unfortunately there is no accepted universal definition of the patient record, and the words CPR, electronic health record, computerized medical record, or whatever means everything from capturing data for reimbursement to complete clinical records. Over 500 vendors claim a computerized medical record as a product. In reality, no healthcare facility enjoys the CPR necessary to meet the needs of the next century.

This tutorial presents, first, a concept model of the CPR and discusses many of the issues relating to such a model - who is developing concept models, how many models are there, is there an in-patient model and an outpatient model, is there a record for each specialty, is the record distributed and is there a master dataset? Can the functions related to clinical care, research, education, administration, and reimbursement be derived from the same record?

Next, the tutorial will discuss details of the CPR. How is the content defined and what is the best way to present that data - an object-oriented approach? National efforts in developing a global patient data model will be discussed. What kinds of data are contained in the patient's record and how are the data organized? The major classes of data include demographic, people involved in patient care, reimbursement data, appointments, summary problems,

studies, therapies, histories and physical examination data, encounter detail, and accounting data. What are the different types of data and how are they represented? Must the CPR be multi-media? What are the requirements for report generation and query? What kinds of data presentations are necessary? What approaches work for the real-time capture of data at the source?

One major component of the CPR is the vocabulary used to express medical tasks and concepts. What coding schemes work? How close are we to a universal medical language? Should data be stored as free text or should data be stored as codes? Who is working on these problems and what progress is being made? How are mandatory differences among specialty groups accommodated? The tutorial will discuss, in detail, a comprehensive data dictionary which defines vocabulary, information flow, user characteristics and privileges, specializations, and decision support algorithms.

What functions must the CPR perform? The CPR must provide data at the place and time it is needed as well as in the proper format. The CPR must organize and manage the flow of data and insure timely awareness and response to important details. Linkages to knowledge bases and bibliographic retrieval systems expand the value of the system to health care providers. How are such systems accessed and how are they linked into the CPR. Decision support algorithms working in the background insure patient care rules are carried out. How are such algorithms defined and how are they carried out?

Finally, real implementations of CPR systems will be discussed. The most common model being implemented today is a client/server architecture. Most CPRs will draw data from a variety of systems. These interfaces among component systems must be generic and seamless. A necessary condition to accomplish this ideal "plug and play" environment is workable a data interchange standard. At least six groups are working to produce components of such a standard: HL7 for clinical data interchange; ACR/NEMA for imaging standards; ASC X12 for reimbursement, benefit and payment plans, and purchasing documents; ASTM for clinical observations and waveform data; NCPDP for drug reimbursement; and IEEE MEDIX for an

ISO compatible patient data model. (The tutorial will even define what all these letters stand for). How complete are these standards and how far have these standards penetrated the vendor market?

As records become more widely accessible through modems, local area networks, wide area networks, and Internet issues of security, privacy and confidentiality become increasingly important. The tutorial will discuss these issues and suggest practical and realizable solutions to the problem.

The tutorial will include examples from a computer-based patient record system - The Medical Record (TMR) - which has been in development at Duke University Medical Center since 1975. The system has been implemented in a variety of settings from primary care, secondary care, tertiary care and intensive care and in academic settings, community settings, group practices, doctors offices, nursing homes, skilled nursing facilities and home health. Combined inpatient and outpatient records are supported as well as a regional database for obstetric patients. TMR supports complete storage of all healthcare related data. Current systems include patient databases exceeding 160,000 patients.

What are some of the practical problems encountered in implementing the CPR? How can data integrity be insured? Are we ready for complete dependence on the electronic patient record? When will we get there?

Basics of Digital Imaging

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- I. Attributes of the Digital Image
 - A. Matrix size
 - B. Bit depth
 - C. Examples of digital images
- II. Acquiring the Digital Image
 - A. Cross-sectional images/direct digital data
 - 1. Ultrasound
 - 2. CT
 - 3. MR
 - 4. Nuclear Medicine
 - B. Capture of X-ray images
 - 1. Direct digital image capture
 - 2. Computed radiography (CR)
 - 3. Film digitalization
- III. Moving the Digital Image
 - A. Network Architecture
 - B. Types of Data Transmission
 - C. Protocols/Standards
- IV. Storing the Digital Image
 - A. Classification of Storage Types Hiearchival Level
 - 1. Immediate
 - 2. Intermediate
 - 3. Long-Term

- B. Classification by Type of Storage Media
 - 1. Magnetic Media
 - 2. Optical and Electro-Optical Media

V. Displaying the Digital Image

- A. Classification of Display Stations by Function
 - 1. Screening Stations
 - 2. Consultation/Review Stations
 - 3. Diagnostic Stations
- B. Attributes of a Workstation
 - 1. Screens/Monitors
 - a. Physical size
 - b. Layout of screens
 - c. Resolution
 - d. Number of screens
 - 2. Interface to workstation
 - a. Light pen
 - b. Touch screen
 - c. Mouse
 - d. Keyboard
 - e. Voice
 - 3. Software capabilities
 - a. Image placement
 - b. Image movement/arranging
 - c. Viewing (window, level, contrast)
 - d. MPR, MIP, cine
 - e. Measurement (distance, ROI)
 - 4. Storage capabilities
 - 5. Hard copy output capabilities of a workstation

The DICOM Standard

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ACR-NEMA Version 3.0, also called DICOM (for digital imaging and communications in medicine) is a standard for communication of medical images and associated data¹. Much of the data structure of the earlier versions of ACR-NEMA is retained. Also, the existing point-to-point interface will continue to be supported. Added are support for network communication, specifically using transmission control protocol/internet protocol (TCP/IP) and the International Standards Organization-Open Systems Interconnection (ISO-OSI) standards. A layered structure for DICOM is retained, and the design is such that the same imaging application can run over any of the supported communications options (point-to-point, TCP/IP, or ISO-OSI)^{2,3}

The increased capability of the standard means that the document is much larger than that of Versions 1 and 2. Following ISO practice and guidelines, the standard will be published in multiple parts. Parts 1 through 9, the basic "core" of the standard, have already passed the ACR and NEMA balloting procedures and are being printed. Work on new parts and annexes for the existing parts is underway. These will cover new information objects (the basic data structure used in the standard) for x-ray angiography, file formats and media for data exchange, and a point-to-point connection for printing devices.

In 1992 and 1993 important demonstrations of DICOM took place in the RSNA *infoRAD* exhibit area. At the 1993 RSNA, the demonstration included manufacturer-to-manufacturer communication and an independent European implementation of the test node (the computer to which the different devices are required to connect). The demonstration used Parts 1 through 8 of DICOM (Part 9, the point-to-point specification was not used since the emphasis was on the network connection). The software developed for the demonstration by the Mallinckrodt Institute has been made widely available at no cost.

One of the major important features of DICOM is that it provides a structure for modeling the way medical imaging is organized. Manufacturers adhering to the standard then understand the meaning of "study", and "patient name" in an unambiguous fashion. The effort of building these models is part of the object-oriented design process. The modeling and use of object-oriented design means that extending the standard is straightforward. The basic information unit of the standard is the information object. This is a structured collection of data elements that describe (in an abstract way) something used in medical imaging, such as the image itself. The

basic operational unit of DICOM is the service class. Services include such actions as "storage" and "query/retrieve" operations. Combining a service with an information object results in a functional pair, the Service-Object Pair (SOP) that is the building block of DICOM communication. Extending the standard means creating new information objects or services. When created, these provide all of the existing services for the new object, and often allow the old objects to be used with the new service as well.

A question facing users is how to go about adding DICOM to equipment purchase requirements and understanding what the vendors mean when they say they are DICOM conformant. The manufacturer conformance statements will clearly identify how they are conformant, and the structure of Part 2 ensures that these claims will have the same overall structure. This will make it simpler for users to compare them and determine if they are compatible. It would also be reasonable for a user to require that perspective vendors meet with the user and explain how their implementations of DICOM would work together. This could, for example, be part of a request for proposal (RFP) or request for quotation (RFQ) when preparing to purchase new equipment.

Interest in DICOM extends beyond radiology. Collaborative work with the American College of Cardiology, other medical specialty societies, and expanded work with the NEMA Nuclear Medicine and Ultrasound sections is further extending the application of the standard. Formal representation on the American National Standards Institute (ANSI) Healthcare Informatics Standards Planning Panel (HISPP) by ACR-NEMA DICOM is in place, and work with HIS standards groups, including HL-7, ASTM, and IEEE MEDIX is ongoing.

DICOM will likely emerge as the major medical image communication standard, and its support from manufacturers is quite strong. The ACR-NEMA Committee works towards standards commonality and harmonization not only with other U.S. standards developers, but also with international groups including CEN in Europe and IS&C/JIRA in Japan. At the end of 1993, the CEN Technical Committee 251 decided to adopt DICOM as the basis for their European MEDICOM effort. In 1994, several joint meetings of ACR-NEMA and CEN have been organized to foster the coordinated further development of DICOM.

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Asynchronous Transfer Mode (ATM) and its Applicability to the Telemedical Environment

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DESCRIPTION

Asynchronous Transfer Mode (ATM) has been chosen by the telecommunications standards committees around the world as the underlying switching and multiplexing technology that would be used within the very high speed (broadband) communications systems that are evolving. It offers the promise of eliminating the barriers between local and wide area networks, providing seamless interconnection of Local Area Networks (LANs) across the country and the world. For those knowledgeable of the issues related to acquiring telecommunications circuits that could be used in the transfer of video images and information related to medical diagnoses, ATM is the start of a process that is predicted to remove one of the typical barriers to telemedicine acceptance by eliminating transmission speed as an issue in acquiring services. ATM offers the capability for flexible bandwidth on demand. Neither circuit switching (commonly used to support voice telephone applications) nor packet switching (a data oriented service arrangement offered by commercial telephone carriers) are considered as capable and effective as ATM switching in satisfying the needs of users that want to process video, data, and voice simultaneously, with minimal delay. Figure 1 illustrates data cells comprised of an asynchronous mixture of video, data, and voice being processed concurrently through a single ATM multimedia switching environment.

This tutorial on ATM will provide the novice in the telecommunications environment with the basics of ATM and its applications. Some basic definitions of the terms used, such as asynchronous, and transfer mode, will be presented followed by a discussion of why we need ATM, how it works (in very straight forward terms), and how is it implemented in today's rapidly changing telecommunications world. The attendees at this tutorial will hear about some of the factors that are making ATM a reality, including a discussion on the efforts of standardizing ATM. Current products that are on the market and services supported by using ATM relative to other types of telecommunications will be identified. Finally, ATM telemedical applications will be described followed by brief multimedia demonstration of an ATM collaborative application using an ATM switch system.

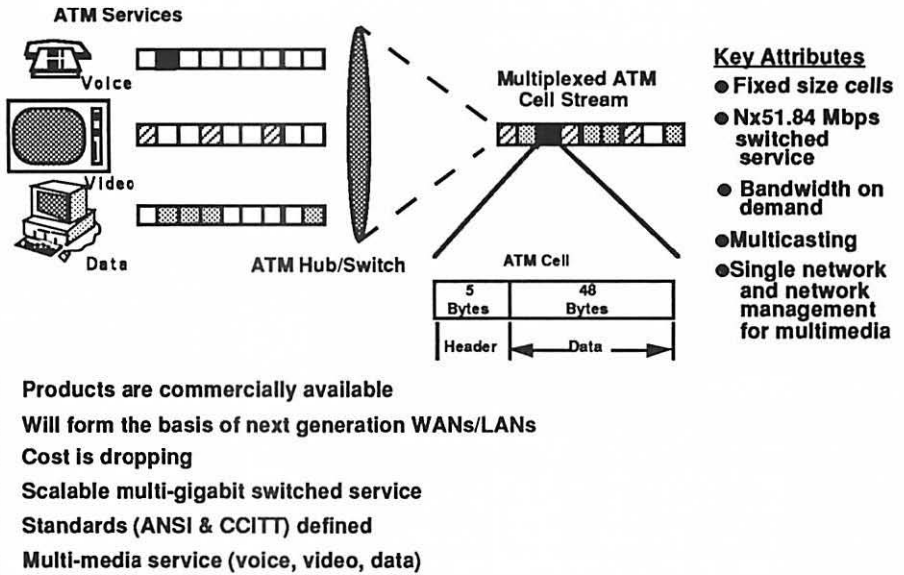


Figure 1. Asynchronous Transfer Mode Operation in a Multimedia Environment

SESSION 1

Wide Area PACS

Chair: Bob W. Gayler

Worldwide Experience with Large PACS Systems

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The term, Picture, Archiving, and Communications Systems (PACS), was first used about 1980. In spite of the benefits, the introduction of practical systems over the last decade and a half has been slow. The single most important reason for this slow development is the complexity of the software required for the systems. The lack of components with adequate capacity and speed has also been a significant problem, and component and total costs also remain as barriers.

Installations of smaller clusters of PACS, known as mini-PACS, are now fairly widely used. Yet there is a common perception that larger departmental systems are not yet feasible. The survey of larger PAC Systems worldwide reported here dispels that belief.

A survey was made of 38 departments with potentially large PAC systems identified through venders and personal contacts.

An immediate problem was selecting a definition of a PAC System. The most practical and thoughtful definition by Dr. Christian C. E. Greinacher was used for this study: "A PACS consists, at least, of one or multiple imaging modalities (acquisition devices), a communication network, an intermediate and/or long term storage device, and an image review and/or post processing workstation."

Still more complicated is identifying what constitutes a large PAC System. As a result of soliciting opinions from many experts in the field, the following perimeters were all offered as useful in defining such systems:

In daily clinical use

Includes three or more modalities

Images available in and outside of Radiology

Number and percentage of included studies

Number and percentage of interfaced primary acquisition devices

Archive size

Not limited to one campus

Only digital interfaces

Filmless operation

Unusual complexity Departmental Volumes

Each individual PAC System presents unique numbers of interfaced acquisition devices, which may or may not be in daily clinical use, and images from which may or may not be archived on the PACS. Some institutions acquire and display images, but do not archive them. Many combinations exist.

The definition of a large PAC System used in this survey employs the first three criteria listed above. The large PACS must include three or more modalities in daily clinical use with images available both inside and outside Radiology. The survey identified 13 institutions with PACS that met this criteria on the survey date of November 1, 1993 as follows:

Large PAC Systems

1987	Landeskrankenhaus Graz, Austria
1988	North Carolina Baptist Hospital
1989	Hokkaido University, Sapporo, Japan
1991	Free University of Brussels
1992	UCLA Health Sciences Center
1992	Madigan Army Medical Center, Tacoma, FL
1992	Shands Hospital, Gainesville, FL
1992	Sozialmedizinisches Zentrum Ost der Stadt, Vienna
1992	University Hospital of Geneva, Switzerland
1992	Wright-Patterson A.F.B. Medical Center
1993	Baltimore VA Medical Center
1993	Brooke Army Hospital, San Antonio
1993	University of Pittsburgh

The first system in clinical use was accomplished by linking hardware components with software developed on site by Professor Guenther Gell and colleagues in Graz, Austria. Nine digitally interfaced acquisition devices covering four modalities provide images to the network, but at present only 14 percent of the images are stored in a long-term archive. North Carolina Baptist Hospital was next, using a commercial system. The granddaddy of the large PAC Systems is the HU-PACS at Hokkaido University in Sapporo, Japan,

developed under the leadership of the late Professor Goro Irie. Clinical operation began in 1989, and substantial portions of this large department are displayed with archiving of many images. Exact numbers are difficult to define, but the percentage of long-term archived images is high. Several other pioneering institutions began clinical operations in 1991. Madigan Army Medical Center, the first of three United States Military Hospitals on the list, began operations in 1992. The systems on the list are a mixture of those developed almost entirely with software done at the institution to those done entirely by a commercial firm and some blending these two approaches.

One of the clear challenges for PAC Systems is directly interfacing acquisition devices. The following table shows the number of digitally interfaced devices by modality at a number of institutions. Older equipment might be interfaced by analog means; those devices are not shown on the following table. Although not meeting the criteria of three or more modality in clinical use at the cut-off date selected for this study (11/1/93), the hospital of the University of Pennsylvania has the most modality and the most acquisition devices interfaced to their PACS. They illustrate each of the seven modality of devices studied. The institutions in this table are shown in descending order according to the total number of digitally interfaced devices.

	CR	CT	DA	DF	MR	NM	US	All	#MOD
Hospital of the University of Pennsylvania (HUP)	2	2	1	2	5	7	11	30	7
Sozialmedizinisches Zentrum Ost (SMZO)	3	2	3	4	0	4	1	17	6
Shands Hospital	1	2	2	0	1	6	4	16	6
Baltimore VA Medical Center	3	2	2	2	1	0	2	12	6
Madigan Army Medical Center	5	2	0	4	1	0	0	12	4
UCLA Health Sciences Center	3	4	0	0	3	0	0	10	3
North Carolina Baptist Hospital	1	6	0	0	3	0	+	10+	4
Hokkaido University Hospital	12	3	1	0	1	0	0	10	4
University Hospital of Geneva	1	2	0	1	1	2	2	9	6

Landeskran- kenhaus Graz	0	5	1	0	2	1	0	9	4
Free University of Brussels	0	1	0	1	2	4	0	8	4
Wright-Patterson A.F.B. Medical Center	2	1	?	3	1	0	0	7	4
Brooke Army Hospital	2	1	0	0	0	0	2	5	3
University of Pittsburgh	1	10	0	0	5	0	0	0	3

Abbreviations include: CR = Computed Radiography; CT = Computed Tomography; DA = digital Angiography; DF = Digital Fluoroscopy; MR = Magnetic Resonance Imaging; NM = Nuclear Medicine; US = Ultrasound; #MOD = number of modality.

As mentioned earlier a number of departments display images of their system for the short-term, but they do not store them in a long-term archive. While the 13 systems identified in the survey are truly large, the percentage of images stored in long-term archive varies markedly. The following table shows the annual number of examinations per year, the bed size, and the number and percentage of studies stored in the long term archive.

	Examina- tions per year	Archived Long Term on PACS	Per Cent	Beds
Baltimore VA Medical Center	42,000	42,000	100%	324
Sozialmedizinisches Zentrum Ost der Stadt	170,000	165,000	97%	580
Madigan Army Medical Center	138,067	120,000	87%	416
UCLA Health Sciences Center	180,000	100,000	56%	600
Wright-Patterson A.F.B. Medical Center	81,000	40,000	49%	205
University Hospital of Geneva	150,000	44,000	29%	1600
Free University of Brussels	130,000	30,000	23%	700
Shands Hospital	151,000	31,600	21%	533
Brooke Army Hospital	190,000	37,000	19%	350
Landeskrankenhaus Graz	160,000	23,000	14%	2,400
Hospital of the University of Pennsylvania (HUP)	225,000	12,500	6%	722
North Carolina Baptist Hospital	221,000	5,490	2%	805

Note that only six institutions meet a criteria of approximately 50 percent or more images stored in long-term archive, namely the first five hospitals in the table above and Hokkaido University. Narrowing the criteria further to approximately 90 percent of the department on long-term archive, only four systems remain: The Baltimore VA Medical Center, SMZO in Vienna, Madigan Army Medical Center, and Hokkaido University.

A Model for the Evaluation of PACS

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I. INTRODUCTION

A small but growing number of hospitals in North America, Europe and elsewhere in the world are implementing PACS. In principle, the work of pioneering hospitals should inform decisions made by the majority of hospitals which have not yet invested in PACS; that is, the pioneers should provide a detailed understanding of its costs and benefits. In practice, however, there are a number of problems in establishing the value of PACS. The most obvious is that few current implementations are being formally evaluated, so that their costs and benefits will not be known. Even where evaluation is being attempted, though, the complexity of the technology itself makes evaluation difficult.

This paper describes the methodology that has been developed in the evaluation of PACS being undertaken in the National Health Service (NHS) in England. The two main study sites are: a hospital-wide PACS at the Hammersmith Hospital in west London; and a system linking radiology to a limited number of departments (orthopaedic and fracture clinics, and orthopaedic in-patient wards) at the Conquest Hospital on the south coast. In particular, the paper focuses on the strategy that is being used to establish links between PACS, clinical processes and changes in patient care. The evaluations have been designed and baseline measures taken. Both systems are due to go live during 1994, and further measurements taken during 1994 and 1995.

II. THE DESIGN OF THE EVALUATION OF PACS

Many clinicians now accept that innovations in health care should be accompanied by careful evaluation. In practice, though, many innovations do not lend themselves easily to evaluation, and randomised clinical trials are not feasible. PACS is a technology which poses a substantial challenge to the evaluator. Experimental studies can not be conducted, since the technology can not be randomly assigned to a number of hospitals - it is too large and expensive to be practicable. This makes it difficult to link the introduction of PACS to observed changes in clinical practice and patient care. Moreover, PACS is a multi-faceted technology, and is used in different ways by radiographers, radiologists and other

clinicians. As a result, it is not possible to assume that any observed effects will result from a single causal mechanism. The task, therefore, is to develop an approach which offers a credible alternative to experimental studies, and which also addresses the problems posed by the complexity of the technology.

Broadly, there are two approaches that might be adopted. One is to conduct detailed quasi-experimental or observational studies of individual elements of PACS, such as those by Kundel and colleagues in Philadelphia¹. These are very valuable in establishing the value of PACS in specific settings such as intensive care, particularly where those settings are deemed to be ones where benefits of PACS are most likely to accrue. If benefits do not accrue there, then the value of PACS is called into question; and if they do then additional work can be conducted in other areas. These studies do, though, leave open the question of the overall value of the more extensive networks which many observers regard as inevitable. A sequential 'case-by-case' approach runs the risk of answers arriving too late to influence investment decisions.

The second approach is designed to address these problems by evaluating PACS as a whole. It is predicated on the assumption that PACS is likely to exert its effects in different ways with different users. As a result, no single study will reveal the value of PACS, and a number of studies of different aspects of PACS are required. It might be that negative results in one area are outweighed by positive results in others, and judgments are required about the overall balance of evidence.

The HERG evaluation of the systems at the Hammersmith and Conquest Hospitals has adopted the second approach. The evaluation has been designed so that the results of individual studies can be combined using a 'triangulation approach'². The orienteering metaphor stresses the concept of using multiple reference points to locate an object's position; researchers combine methods to improve the accuracy of their judgments. The assumption is that the (unavoidable) weaknesses of individual methods can be overcome when results are carefully combined. In the case of PACS, the further assumption is made that the approach can be used to describe and explain causal links; judgments about PACS depend on understanding these links, and so merit close attention. For example, a single study of PACS in an out-patient clinic might demonstrate reductions in resource use. By comparison three careful studies, using different methods, each converging on the conclusion that PACS leads to reductions in resource use, are that much more convincing. (Note that this in no way constitutes a proof; it should, though, give people deciding whether or not to invest in PACS more confidence in their judgements.)

The triangulation approach has often been used in evaluations of health care. Anderson and colleagues³ promote the use of multiple methods in the evaluation of information technologies, and present examples of different methods applied to a range of technologies. There appear to be few previous examples of the use of the triangulation approach for a single information technology, and none of a digital imaging technology.

III. LINKING CAUSE AND EFFECT

The process of linking PACS and its effects can be outlined as a four stage process.

1. The first step is to examine the overall organisational context for the implementation of PACS, since this may influence the distribution of costs and benefits in time and across an organisation, and hence where they should be sought by evaluators. It is possible to imagine four distinct possibilities.

Direct influence on clinical behaviour. The effects of PACS may be conceptually straightforward, and causally influence clinical behaviour and patient care.

Clinical behaviour forces changes in the technology. If users are determined not to change their behaviour, then they may insist that PACS is modified to reflect their current practices. If this occurs then benefits will not be realised. Anecdotally, there is evidence that this often occurs when computer systems are implemented⁴. The point emphasises that PACS is not an immutable technology, and like information technologies in general can be modified in line with the wishes or needs of users; it would be naive of evaluators to imagine otherwise.

Organisational change precedes implementation. Some writers on organisational change argue that benefits only accrue from the introduction of information technologies when the organisation is prepared in advance, and then the technology is introduced to facilitate and consolidate a desired change^{5,6}. If this preparatory change phase is omitted, it is argued, the system will achieve few benefits or even be rejected. If this view is correct, and a primary driver of change is organisational, the nature and timing of benefits may be very different to the first case. Indeed, important benefits may be realised before the technology is implemented.

Interplay between PACS and clinical behaviour. The fourth possibility involves users developing an understanding of how to exploit the new

technology over time. Where software updates and redesign can be undertaken rapidly, PACS may also be continuously modified to support improvements in patient care. This may occur in combination with one or more of the other possibilities.

The HERG evaluation focuses primarily on the first of the four, though the second and third are being investigated qualitatively. The fourth pattern, while potentially important, is particularly difficult to monitor; it will be investigated where possible.

2. Second, it is possible to imagine PACS being associated with distinct patterns of change at the point where the system 'goes live'.

Step change. PACS is associated with a step increase or decrease in performance. This pattern might occur in circumstances where the technology itself is the agent of change through an automation effect; or where there is a significant change in the quality of information available.

Gradual, unidirectional change. PACS is associated with a gradual, medium-term increase or decrease in performance. For example, a positive change might occur where users are learning how to exploit PACS; that is, usage is related to a medium-term learning process.

Variable change over time. PACS is loosely associated with observed changes in clinical practice or patient care. This might occur in circumstances where PACS (and perhaps radiology in general) is only one of several important inputs to service delivery, and other factors influence the usage of PACS.

It is probable that each of these three patterns can be found in different parts of a hospital at different times, particularly in the early period of operation of a system. The HERG evaluation has elected to focus mainly on step changes. The turbulence of the NHS in England in the wake of major reforms means that analysis of data over a time period of a few years is difficult, and so the presence and order of the other two patterns would be very difficult to establish; time series data are being collected to test whether any effects can be established, using an interrupted time series design.

3. In practice, it is not possible to study all possibilities, and the last two steps are designed to address this problem. The third step involves the development of a model to assist in the identification of appropriate methods. It should be stressed that this is a *research* model intended to

help design a research programme, and does not make any specific assumptions about the likely costs and benefits of PACS. Since a key objective is to be able to comment on the causative links between PACS and clinical behaviour and patient care, the model seeks to identify essential links without presuming their scale or direction.

Figure

Research model of the costs and benefits of PACS

Input	Process	Behavioural Outcome	Service Outcome	Final Patient Outcome
Mix of staff and other resources	Turnround time for x-rays	Usage of radiology service changes	Number of patients seen increases	Possible benefit: more patients appropriately treated
Mix of staff and other resources	Use of CR	Clinical and radiography practice changes	Radiation doses reduced	Calculated increase in life expectancy

The Figure is a modified version of the classic structure-process-outcome model, extended by Rossi and Freeman⁷. By itself, the model does not indicate which methods should be used to test which patterns of change for particular elements of PACS. The model suggests though that multiple methods should be used to establish, as nearly as possible, causal linkages in different parts of the hospital. Different strategies were used to identify the most appropriate methods. One was to canvas 'expert' opinions within the case study sites and elsewhere, particularly about the areas of a hospital where PACS might have its greatest impact on resource use or patient care, and the aspect of the service which might be affected. The term expert is used advisedly, since PACS is too new and innovative for anyone to be sure of patterns of costs and benefits, but future clinical users and technical specialists are clearly in a better position than most to make informed judgments about PACS. These discussions suggested *inter alia* that the radiology department, intensive care, accident and emergency services and outpatient clinics might change substantially when PACS was turned on. A second

strategy was to select services which, in combination, provided a reasonably representative spread of services; for example, it was thought important to include at least one medical and one surgical specialty since their use of medical images differs in important ways. In effect, a purposive sampling strategy⁸ was used; there was no definitive way of making these selections.

Then, in common with other case study evaluations⁹ a number of hypotheses were identified which could be tested for specific services. As far as possible, the hypotheses were generated from well established theories, or null hypotheses were postulated about the impact of PACS on a particular service. For example, an economic perspective led to hypotheses about the relationship between PACS and in-patient length of stay and resource use in out-patient settings, and quantitative studies were designed to test them. The literature on the relationships between information technologies and organisations⁵ led to hypotheses about the relationship between the way that the technology was implemented and the order of benefits that would be achieved. And, the belief that investments in PACS will be justified only if they bring substantial benefits to patients led to the design of studies which measured patient outcomes directly or provided the best achievable proxy measures of outcome.

Individual studies were, then, designed to illuminate particular aspects of PACS. What most did not do, however, was provide the desired links between inputs, processes and outcomes. With regard to the immediate impact of PACS on clinical work, qualitative methods such as cognitive mapping¹⁰ are included to help draw causal links between processes (using PACS) and intermediate outcomes (changes in behaviour of clinical users). These methods were designed to provide the 'glue' between boxes in the model, and hence contribute to understanding why other (quantitative) results were found.

4. The more general approach to the problem of causation is the focus of the fourth step, the triangulation, involving combination of the methods to make comments about the overall value of PACS. The evaluation was designed, within practical constraints (such as researcher time and access to specialties), to facilitate combination of results in a way that maximises understanding of causal links. The model includes examples of linkages, which show that combinations of different quantitative studies, and of qualitative and quantitative studies, are both used to link causes and effects. So, if some studies suggest that clinicians do not change their practice when PACS goes live, then doubt is cast upon the likelihood that other observed changes are due to PACS. If, more

positively, turnaround times for images being produced for intensive care patients are reduced, and length of stay in intensive care is also reduced, then PACS may be responsible for any associated reductions in resource use. Similarly, if it is shown that in-patient length of stay falls when PACS is turned on, and an interview programme with relevant clinicians eliminates any obvious confounding effects (eg introduction of a new pharmaceutical at around the same time) then the possibility that PACS is wholly or partially responsible is enhanced.

Adopting a slightly different type of argument, there is a degree of overlap in the hypotheses being tested in different clinical areas. For example, the extent to which digital images change the effectiveness of diagnosis (compared to conventional film) is being tested in different ways in an accident and emergency setting and for an elective orthopaedic condition. If these point in the same direction, then the underlying hypothesis being tested (that the digital images are no different to conventional images for diagnosis) is more strongly supported than if only one study were being conducted. Of course, if the studies point in different directions then a more complex hypothesis may be required, or further work undertaken to enhance understanding.

IV. CONCLUSIONS

It can not be stressed enough that this approach will not prove that particular causal links have been correctly identified, and hence conclusions about costs and benefits of PACS will be presented with important caveats attached to them. To some extent this reflects the fact that PACS is so novel, and there is relatively little prior experience or published work to inform judgments about causation. Even more important is the complex nature of PACS, which precludes more rigorous research designs.

The evaluation will, though, help to resolve some of the many detailed questions about the economic and clinical value of PACS. Presented as individual papers, the results should help to illuminate specific issues. Together, they will contribute to the process of forming overall judgments about PACS; better understanding of causal links will be a crucial element in forming those judgments. The evaluation described here is, therefore, probably nearer the beginning than the end of the debate about the value of PACS.

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Clinical Routine Operation of a Filmless Radiology Department: 20 Months Experience

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I. INTRODUCTION

Since almost 2 years the concept of filmless radiology on the basis of a large scale PACS has been realized in clinical routine in a major teaching hospital with currently 560 acute-care-beds.

Filmless radiology implies that all image acquisition sources are intrinsically digital, all exams reported from monitors, and the resulting product "image & report" communicated and archived in digital format. This fully digital infrastructure in the hospital has proven to be reliable and safe in clinical routine.

Since 1990, this PACS has been developed by a single major manufacturer (Siemens Erlangen, Germany and Vienna, Austria) in cooperation with the radiology staff of the Danube Hospital. In Europe, PACS is primarily a user-driven technology, in particular radiologists, who set up *functional* rather than technical requirements in taking advantage of the upcoming new developments in computer- and information sciences. The way PACS is planned determines its performance in routine operation: so the involvement of radiologists right from the earliest planning stages is a *conditio sine qua non* for its successful implementation !

After having set up the PACS eventually other digital systems - such as the Radiology- and the Hospital Information System (RIS and HIS) and a digital Speech Recognition System, from different vendors - have been coupled with the PACS to ensure an integrated clinical operation and increase the efficiency of our department.

The feasibility of filmless radiology already has been documented in literature, and is not the object of this presentation ¹⁻⁶. It is rather the issue of benefits and justification of PACS, which is controversially discussed in the literature ^{1, 7-9}. This paper aims at contributing to this debate by providing facts and data based on our experience.

So far (status: February 1994) 586.047 digital images have been generated resulting in 1,3 Terrabyte of data stored on optical disks. Currently the daily data production is 5 to 6 Gigabyte and the network traffic (archiving, communicating, retrieving) is 15 to 18 Gigabyte.

II. OVERVIEW OF CURRENT IMPLEMENTATION

- * 3 DLR-systems (2 Digiscan 2H[®], 1 cassetteless automatic chest unit - Digiscan 2T[®])
- * 5 digital fluoroscopic units (all with Fluorospot H[®])
- * 8 ultrasound units
- * 5 mobile x-ray units
- * 3 angio suites (1 biplane digital coronary angio HICOR[®], 1 Angiostar[®] and 1 Multiscop[®], each with a Polytron[®])
- * 2 CT (1 Somatom Plus S[®] and 1 AR.T[®])
- * 16 diagnostic reporting consoles with 2 to 6 monitors in the radiology department (DRC 102, 104 and 106[®])
- * 26 peripheral image viewing consoles at the wards and outpatient clinics
- * 3 speech recognition systems (IBM Speech Serie[®]) with interface to RIS
- * 1 teleradiology system (Photophone[®], Image Data Corp.)
- * 2 camera servers (SIENET CS[®])
- * 1 film digitizer (Lumisys[®])
- * Hospital information system (KIS-WIKIS MDADV, Vienna)
- * Radiology information system (SIEMDOS[®])
- * HIS-RIS-PACS-Interfaces
- * PACS (SIENET[®], Siemens) based on a double ring FDDI backbone
- * Open system based on standards (ACR/NEMA, DICOM extension and SPI specifications)

III. EXPERIENCE IN MONITOR REPORTING

It is one of the key issues of filmless radiology to be able to rely on monitors for reporting radiological exams. The necessary technical requirements are defined by the diagnostic accuracy of monitor that has to be at

least equal to film based reporting. The monitors of our installation correspond to these requirements with a high luminance of 175 FL, flickerfree image (72 Hz), a CRT size of 21 in., and a spatial resolution of up to 2000 lines.

In our experience it is of great importance that the reporting rooms are not dark but moderately lightened, otherwise the radiologists sitting in front of the diagnostic consoles complain of early fatigue and eye strain.

Own studies have shown that the monitors of the reporting consoles have diagnostic superiority over laserhardcopies of digitally acquired images and show equal diagnostic performance as optimal exposed conventional film-screen systems ¹⁰. This is even true for mammography, a radiological procedure placing the highest demands on an image display system ¹¹.

Although the diagnostic reporting console has a variety of features to evaluate, display and postprocess images, in routine operation there is very limited need felt to utilize evaluation procedures other than the following:

- * For digital luminescence radiography (DLR) images such as chest and skeletal exams, and for fluoroscopic and angiographic images: (1) window and level adjustment (to evaluate structures with different x-ray absorption) and (2) distance.

- * For Computertomography: (1) window and level, (2) measuring region-of-interest values, (3) distance measurements, (4) reformatting, reconstruction and 3-D display.

More sophisticated postprocessing of DLR images concerning contrast (manipulations of the gamma-curve) and spatial frequency (unsharp masking, frequency rank, enhancement factors) is very occasionally performed in questionable cases, e.g. to enhance rib structures in a chest exam when a fracture is indicated, but more often utilized in comparative studies of diagnostic accuracy.

In general these postprocessing capabilities so far have not significantly increased the diagnostic quality of radiological exams in routine operation (partly also due to the increased amount of time necessary to perform this kind of work), yet in our opinion these features have not fully been exploited so far. Furthermore, the use of expert systems in radiology to increase the diagnostic performance (e.g. microcalcifications or stellate lesions in the breast, or nodules in the lungs) and more advanced image postprocessing methods (segmentation, fusion) have not reached a level where a routine application is possible in a clinical setting.

IV. INTEGRATION ISSUES

The work of reporting radiological cases demands access to (1) images of the exam to be reported, (2) exam request with patient data and the diagnostic question. Furthermore in case (3) previous images as well as (4) previous reports are available, these may contribute to the understanding of a case, and therefore must be easily and rapidly accessible. While some data are stored in the PACS others are in the RIS and/or the HIS. It was a radiologist's requirement from the earliest planning phases to integrate all these systems in order to form one functional entity where relevant data are accessible regardless where stored¹². During the first phase of our clinical operation 1992/93 there was only a rudimentary coupling of PACS and RIS via a magnetic card, that matched image and patient data. The lack of the fully integration made it necessary to access data of the same procedure at different terminals. Thus beside each PACS console a RIS terminal was installed. This meant double data entries to access the relevant information, thus increasing the time spent to report a case. Recently a gateway between the PACS and the RIS has been installed, that enables the radiologist to access previous reports by clicking the "report"-button at the PACS console. What remains is the radiologist's demand to have an "exam request"-button as well, which of course implies the further development of the PACS-RIS interface.

The exam request is entered into one of 250 HIS terminals on the wards and in the outpatient clinics, and electronically transferred into the RIS, where a technician schedules the exams. Worklists for the different exam rooms and for the patient transportation service are created. The exam is administrated in the RIS, billing is performed in the HIS, which could be done in the RIS as well.

The report, as soon as it is finalized either by the secretary or one of the speech recognition computers, which are coupled with the RIS, can be electronically transferred to the ward's HIS terminals, but most of the wards still prefer the report as a printed document. Nevertheless the electronic access to the report in the HIS might save a lot of unnecessary phone calls, as every radiologist easily can imagine.

Full systems integration takes advantage of certain actions performed in one system to trigger events in the other. As an example: the scheduling of an exam will trigger the prefetching of previous exams of the same type to an allocated workstation, where it automatically is displayed together with the new exam. The same is true for the "post"fetching, which means that the generation of the final report triggers the transfer of the reported image to the respective server on the ward, where it - together with the report - is accessible

from the ward's viewing stations. These are requirements that have to be met soon, in order to relieve the radiology staff of the work of sending images to peripheral viewing stations or preloading case conferences. These were only a few examples of what is left for a "PACS project" rather than the PACS experience.

V. TIME PERFORMANCE

To assess the time performance of analogue versus digital operation our department was compared to 2 filmbased teaching hospitals in Vienna (Krankenhaus Rudolfstiftung and Krankenhaus Lainz). Various routine tasks, concerning the handling of images - so primarily organizational issues in a radiology department - have been evaluated and compared. It does not include the reporting time and other tasks (such as teaching) of the radiologist: For "general" radiological exams such as the skeleton PACS saved 25% of the time used in the film based systems (table 1). For the cassetteless chest examinations PACS saved 45% (table 2), and digital fluoroscopy exams were 32% faster than filmbased fluoroscopy (table 3).

Table 1. Time performance of skeletal, abdominal and portable exams, using 2 cassettes:

DIGITAL (storage phosphor technology)	min.	ANALOGUE (conventional film)	min.
transport cassette	0,25	transport cassette	0,25
write magnetic card	0,50	write/print scribor	0,50
data entry (image ID), image read-out, quality check	2,50	film ID (scribor), film development, quality check	3,25
finalize exam in RIS	0,25	film administration, ID film jacket	0,75
		transport film to reading area	0,25
	3,5		5,0

Table 2. Time performance in cassetteless chest exam units:

DIGITAL (storage phosphor technology)	min.	ANALOGUE (conventional film)	min.
write magnetic card	0,50	write/print scribor	0,50
data entry (image ID)	0,25	film ID (scribor)	0,25
quality check	1,50	film development	2,75
finalize exam in RIS	0,25	quality check	0,25
		film administration, ID film jacket	0,75
	2,5		4,5

Table 3. Time performance of fluoroscopic examinations:

DIGITAL FLUOROSCOPY	min.	ANALOGUE (conventional film)	min.
enter patient data	0,25	transport cassette	0,25
image selection, postprocessing	3,00	write/print scribor	0,50
send selected images to workstation	0,50	film ID (scribor)	0,25
		film development, quality check	3,50
		film administration, ID film jacket	0,75
		transport film to reading area	0,25
	3,7		5,5

The radiologist's reporting time itself, i.e. the time an image is read and a diagnosis is dictated, currently increases with PACS by approximately 20-50%. This is primarily due to the fact, that still there is no prefetching and previous images have to be retrieved by the radiologist, which adds an extra 15-45 seconds period to the reporting time for each case. This is the reason that soon a prefetching mechanism - explained earlier in this paper - will be introduced. Nevertheless for reading new cases without previous images the reporting time is almost the same as with a preloaded alternator, because while reporting an exam the next patient on the worklist of unreported cases already is preloaded into the RAM and immediately is available by clicking a button.

So to achieve the same reporting time as a preloaded alternator following features will have to be implemented, which are:

- * 1. prefetching images related with the current exam,
- * 2. when a new exam is selected, automatic display of:
 - 2.1. current exam request, and
 - 2.2. relevant old images.

Together with automatic preloading the next current exam into the RAM no preloaded autoalternator will beat this system. We expect this to be the case in summer 1994. By then, taking into account the shorter examination times already achieved (tables 1-3), the electronic infrastructure will be superior to the filmbased system concerning time performance.

VI. CHANGES DUE TO PACS AND RELATED BENEFITS

As one can see from the paper so far, PACS primarily serves as a tool in the handling of images and patient / exam related information. The great difference - and the advantage - of PACS is the constant and reliable access to this information, which increases efficiency in the radiology department and the quality of patient care. This is easy to investigate when one thinks of the time (and nerves) spent in searching old or even newly acquired images for reporting or for organizing a case conference. How many exams have been repeated due to lost images ? In a society increasingly aware of medicolegal issues, what are the implications of this ? Furthermore in evaluating PACS one cannot just compare the almost 100-years old filmbased system with an electronic system. One has to anticipate *changes* in the development of radiology and medicine in general. You have to consider that medicine is changing tremendously. MR is just an example that new procedures mean increasing amount of data. Medicine more and more is data accumulation. Electronic systems by selecting the appropriate query parameters allow fast and easy selection of the relevant data for the task to be performed. No conventional archive system can cope with that.

So the benefits of PACS and the changes it brings about have to be seen from this point of view by anticipating the changes already happening in medicine instead of a rather static comparative attitude. This means that PACS is not just the replacement of film, but that a film based organization in medicine will not be able to handle the task medicine demands already today, and even more in the near future.

Finally some parameters concerning efficiency of the department and medical benefits that we have experienced are listed:

- * We have shown that PACS reduces the examination time and how it soon will be capable to reduce the exam-reporting time as well.
- * Very short report turnaround time (3 minutes for ICU, 5 minutes to a maximum of 12 hours for all other exams for in-patients). The department's policy of delivering the report on the same day the exam is performed could easily be achieved with PACS infrastructure.
- * Our hospital has the shortest hospitalization time in our country: 6.4 days (including the ICU, excluding out-patients) versus 8-11 days in comparable hospitals.
- * visitors of our department often mention the absence of a hectic atmosphere due to good organization and probably primarily due to the absence of personell hastening around with films or in search of them, which often is the case in conventional departments.

* Improvements in our teaching organization by easily generating so called "Teaching folders" to organize cases for residents and students

* Teleradiology system which connects another hospital to our department, mainly used for expert consultation or when patients are transferred

* 3 *speech recognition computers* are used for times when no secretaries are available (nights and weekends). These are coupled with the RIS and enable very simple and fast report generation and delivery. The correct word recognition rate is tremendously high (average 93%).

VII: WHAT IS LEFT ?

As already mentioned in this presentation the full integration of all digital subsystems is on the way. At the moment when we are able to remove the RIS-terminals beside the PACS reporting consoles this goal - always required by the radiologists - will be achieved.

Intelligent software to support the reporting process by prefetching images (to the reporting console), postfetching (to the ward's workstation server), correct image presentation on the screen, and the automatic anticipation of certain tasks will make PACS superior to the conventional system also concerning time performance (comparison with a preloaded conventional autoalternator) as it already is superior in other fields mentioned earlier in this paper.

PACS provides the reliable infrastructure for additional computer and informatic applications aiming at improving diagnosis and treatment for the benefit of the patient.

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First Clinical Experiences in a Digital Radiology Department

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1. Introduction

Thornton Hospital became operational in late 1993. It is a new hospital which is part of the University of California San Diego system, sited 10 miles from the main University Hospital in Hillcrest, near downtown San Diego. Thornton Hospital is designed for general medical and surgical services, with an emphasis on oncology, orthopedics and cardiovascular surgery.

All the modalities will be connected to the network. For now, CR, Digital Fluoro, CT and MR deliver images to the softcopy interpretation workstations. Later this year, Angiography, Ultrasound and Nuclear Medicine will follow.

We will report our early experiences with softcopy diagnostic image interpretation. The parameters we are looking at are image quality, ease of use, image interpretation time as compared to the film alternator and system acceptance by both radiologists and clinicians.

2. Configuration and Procedure Volume

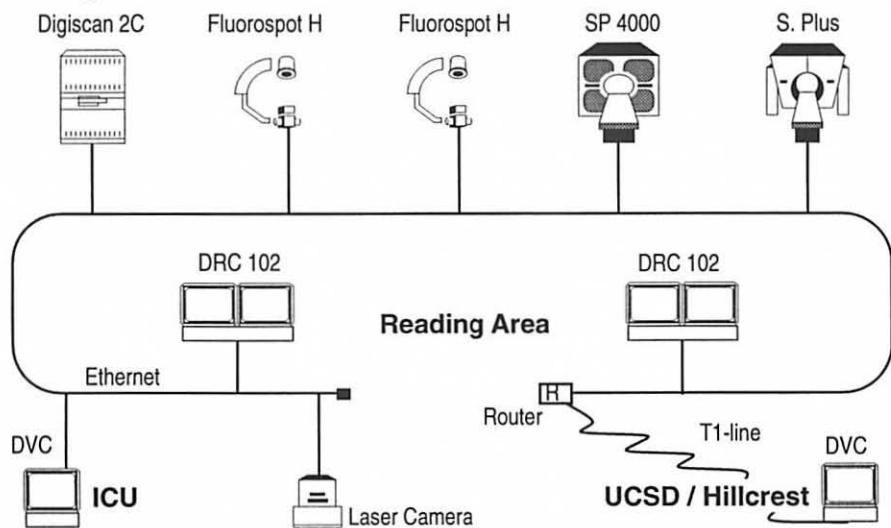


Fig 1: Configuration.

The initial configuration, already operational, is shown in Fig 1. Two softcopy diagnostic interpretation workstations share the workload of 5 modalities. Images are forwarded to the ICU to a DVC 101 (1 Display Review Workstation). For occasional remote overread and expert consultation, another DVC located in the main radiology department of UCSD in Hillcrest connects to the network thru a T1-line. All the Workstations are equipped with high brightness Simomed-Monitors (up to 175 fL). One Laser Camera connects to the network to print all the CR-images and periodically images from the other modalities.

Table 1 shows the according procedure volume for 100% utilization of the hospital. The current utilization is in the range of 50-70%.

	exams/ year	ima/ exam	ima/ film	films/ exam	films/ year	MB/ exam	MB/ day	GB/ year
CR	29,000	2.5	1	2.5	72,500	20	1,933	580
Fluoro	7,500	10	6	1.6	12,000	10	250	75
CT	2,400	60	12	5	12,000	30	240	72
MR	1,600	110	12	9.16	14,656	14	73	22
TOTALS	40,500			2.74	111,156	18.5	2,496	749

Table 1: Procedure Volume

3. Clinical Experiences

Our early experiences with the imaging network has been positive. The images have been of acceptable diagnostic quality. The portable chest images in particular have been well received both by the radiologists and by the clinical staff. The specifics of use of the imaging network are outlined below.

3.1 Computed Radiography

The image quality at the workstation (WS) has been very acceptable. There are definite advantages of being able to window and level the images on the workstation. Most of the cases have been portable ICU films. The spatial resolution has been adequate. The use of the "magnifying glass" to magnify portions of the image have allowed us to easily evaluate the 1K image presentation for the presence of pneumothoraces.

The postprocessing which is done at the WS primarily involves window and leveling adjustments. Although there is the capability for utilizing different gamma correction and spatial filtering, this is not used on a routine basis.

Reading studies at the WS requires a relatively long learning curve. Familiarity with computer keyboard and computer "mouse" manipulation facilitates the use of the workstation. The use of nonphysician personnel to prepare for reading sessions is beneficial for efficient use of physician time. When the studies are organized prior to a reading session, the time for actual reading of an image is only slightly longer than that of conventional film reading. Software improve-

ments need to be made in order to organize files for comparison of old images with the current study more quickly and efficiently.

The images are distributed to the ICU for display on a monitor which is at the nurses station in the unit. This has been quite well accepted, but again requires a period of adjustment and learning. Designating personnel to helping train the ICU staff and to answer questions is crucial. As the ICU monitor is used more frequently, the clinical staff saves time by viewing the images in the ICU rather than making the trip to radiology to view films.

Using CR plates for obtaining images has been well accepted by the technical staff. Software changes to allow barcoding or direct transfer of information from the radiology information system to the imaging network need to be completed.

3.2 Digital Fluorography

The speed of accessing digital fluorographic images on the WS has been very acceptable. The image quality again has been more than adequate. Having a separate workstation allows for additional image manipulation outside of the fluoroscopic room, thus allowing the technical staff to proceed with the set up for the next patient. This allows for increased patient throughput. The separate workstation also allows for clinical consultation on several patients without having to obtain films from the file room for each patient.

3.3 CT

The image quality for CT is not an issue. There is a significant time requirement for each radiologist to develop a format which is comfortable for image review and interpretation. The system has the capability to allow various modes for viewing scans and not all modes are equally acceptable to each radiologist. This is not a problem in terms of the capabilities of the equipment, but does require that the radiologists invest time and effort into creating the optimal display mode. When this optimal display mode is developed, the speed of image review and interpretation is considerable improved. More effort will need to be invested in determining the optimal configuration for simultaneous viewing of current and past studies.

The ability to transmit studies to a remote site for consultation or overreading has been helpful. We will soon be transmitting images to a second site for interpretation of after-hours studies. The use of remote stations requires a high-speed data link.

3.4 MRI

The image quality of the MRI images has not been an issue. The transmission of images from the scanner has some difficulties which need to be addressed by new software. Images are not transmitted with the correct window settings and require image manipulation prior to interpretation. Software enhancements are needed to be able to easily select multiple sequences for view-

ing. Ideally these should be preprogramed so that sequences would automatically appear on the screen in the predesignated viewing mode. Thus, T1, T2, and proton gradient views would be arranged automatically for viewing.

As with CT, some time and effort needs to be expended for developing a comfortable viewing display for each radiologist. The equipment is quite flexible and easily allows for this customization. When the display parameters are in place and when there are software upgrades which allow for better, automatic image arrangement, the image interpretation time should be considerably improved. Time for interpreting studies may then approach that of using a film alternator. Using the workstation has however, the additional advantage of being able to perform image manipulation while reviewing the images.

4. Conclusion

Our early experience with using a workstation for interpretation of studies has been positive. However, there remains considerable room for improvement. In terms of physician acceptance, familiarity with computer keyboard, "mouse" technology and graphic displays help to speed the learning process of interfacing with the workstation. There needs to be a time investment for developing the most comfortable viewing displays for each individual radiologist. This is particularly true for the studies with large numbers of images such as CT and MRI.

Physician acceptance of interpreting CR studies on the workstation has been good. The siting of the remote workstation in the ICU has been warmly received, and is being increasingly utilized. Other services are eager to have a workstation in their clinics. The ability to transmit images to another site for consultation, teaching, or offsite interpretation has been useful. Connectivity of all imaging modalities, i.e., angiography, nuclear medicine and ultrasound needs to be completed. Having all the modalities on line would enhance the continuous use of the workstation rather than the intermittent use which now occurs.

Software modifications are still required. There needs to be easier, automatic sequencing of studies. This is particularly true with current MRI studies, but is also a problem with the viewing for previous exams. Interfacing with the radiology information system is crucial to improve ease of use of the CR unit. It would also allow for the transmission of reports with the images to remote sites such as the ICU.

The optimal physical configuration of the workstation is still under study. The number of monitors, position of the monitors and other ergonomic considerations deserve future investigation.

Implementation and Experience with a Filmless Positron Emission Tomography Center

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I. Introduction

The Positron Emission Tomography (P.E.T.) Center at The Bowman Gray School of Medicine performed its first patient scan in January 1992. Since that time, we have performed in excess of 800 PET scans. The PET scanner is a Siemens ECAT 951/31. It can simultaneously acquire 31 contiguous slices over a 10.4 cm axial field of view with approximately 6 mm spatial resolution. Also located in the P.E.T. Center is a Siemens MultiSPECT 3 three-headed single photon emission computed tomography (SPECT) camera.

The host computer for the PET scanner is a Sun SPARC 2 which is located in the control area directly adjacent to the scanner. Online data acquisition is controlled by a Motorola (MR) 68000 processor. There are 2 Sun review stations, one a Sun SPARC 2 and the other a Sun SPARC IPC. The host computer for the MultiSPECT 3 is a Siemens ICON, based upon an Apple Macintosh Quadra. In addition to these computers, there are 2 Sun SPARC IPCs, 3 Apple Macintoshes and 9 PCs.

Early in the design of this Center, we decided that we wanted to operate in a filmless manner. This was for all of the obvious reasons such as data reliability and accessibility. We also wanted to have our computers all networked such that all users had access to all of the available data. Connection to the rest of the Radiology Department, was an important consideration.

Once it was decided that the P.E.T. Center would be filmless, a number of design criteria were established. Some of the basic criteria included:

- the ability to connect Suns, PCs and Macintoshes into the network,
- transparent data sharing among the three primary computer platforms,
- adequate data and network reliability,
- adequate display software to make diagnoses from the computer screen,
- a data base management system containing information on all aspects of our operation including patient demographics, referring physician information and study results and
- connection to others in the medical school particularly MR and nuclear medicine.

There were a number of secondary considerations including electronic mail, access to the Internet, and the ability to display images in the departmental conference room. All of these factors entered into our design.

The issue of reliability is not one to be taken lightly. There is one level of reliability that is adequate if a film exists on all patients and another when the only images available are those stored digitally. One concern is the ability to retrieve image data previously acquired. This requires the archiving of data in at least two separate locations (a "mirrored" archive). In this manner, if one copy is lost the other is still available. Another issue is the ability to acquire patient data or review previous patient data if the computer network is down for some reason.

Based upon these criteria, a filmless P.E.T. Center was designed. The basic components of this system are as follows:

- a 10 Base T Ethernet hub would be the backbone of the system,
- Sun Network File System (NFS) along with versions for the PC and the Macintosh would be used for file sharing between the various nodes,
- rewritable optical disks and magnetic tape would be used for system archive,
- the P.E.T. subnet would be connected to those in Radiology MR Research through thin-wire Ethernet and through them to the rest of the Radiology Department, the Medical Center and the Internet, and also to the Nuclear Medicine Division through a fiber optic link,
- DBase IV would be used for the P.E.T. Center database management system and
- software would be developed to enhance the diagnostic capacity of the Siemens ECAT software.

II. System Description

A. Network Description

Figure 1 illustrates the basic components of the P.E.T Computer system. The system currently contains 5 Sun computers, four Macintoshes (including the Siemens ICON), an Apple Laser writer and 9 PCs. All computers within the network have Ethernet interface boards and 10 Base T transceivers. The backbone is provided by a 10 Base T hub. All of the phone jacks within the P.E.T. Center are connected to the phone closet via category 5 wire. It is important to use adequate wiring (for 10 Base T use category 3-5) in the design of such a system in order to reduce noise which can slow down your network or make it inoperable. All of these lines are plugged into a 3Com Multiconnect 10 Base T hub which is located in the phone closet. Any computer can be moved to a new location within the P.E.T. Center by connecting the computer to the nearest phone jack and making sure that the jack is connected to the hub in the phone closet. This hub is then connected to the computer network in MR Research through a thin-wire Ethernet connection. MR Research is located in the same building as the P.E.T. Center but up one floor. MR Research is then connected to the Internet and to the rest of the Medical Center. A bridge isolates

all of the computers in this building from the rest of the Medical Center. In addition, the PET subnet is connected to the Nuclear Medicine Division located in another building through an optical fiber link.

Within the system, NFS is used for file sharing. In this manner, the clinical data can be reviewed from any of the Sun workstations within the Center. A version of NFS for the PCs developed by Sun, PC-NFS, is used. This allows the PCs to utilize one of the Sun Workstations as a file server. A file system designated "/home/public" is mounted such that all the PCs have access to it. On the PCs this file system is referred to as drive J:. Thus, files placed on J: are placed on the Sun and are available to all PC users within the system. For example, the file J:\test\junk.txt can be accessed by all PC users by that name. On the Sun, it is referred to as /home/public/test/junk.txt. For the Macintoshes, NFSshare developed by Intercon is used. In this case, the mounted file system appears as a disk icon referred to as Public. In the above example, the file, junk.txt, would be on Public in a folder named "test". Thus the same file can be accessed by Suns, PCs and Macintoshes. In addition, PC-NFS and NFSshare both support the TCP/IP functions, ftp and telnet, as well as electronic mail.

At present the image data can be reviewed from any of three review stations: two in the reading room and one in the Radiology Conference Room which is located in a separate building. This conference room workstation is interfaced to a Barco projector system, such that the PET studies can be interactively reviewed in conference. In addition to these, the scanner host Sun workstation and the 2 programmer workstations can be used to review image studies.

B. Archive Description

Our system utilizes a distributed image database with a single study being archived on various media in various forms. When the data are acquired the raw (sinogram) data are stored on a hard disk associated with the MR 68000 acquisition computer. Within the first day, these raw data are eventually archived onto 4 mm helical tape. After these data are reconstructed into a contiguous set of transverse images, they are then stored on a 660 MB disk associated with the scanner's host Sun workstation. Therefore, within minutes of the completion of the study, the data reside in two separate locations. By the end of the first day, these image data are archived onto rewritable optical disks for permanent storage. Write once read many (WORM) optical disks could have been used for this purpose, but the rewritable optical was provided with the PET scanner. At midnight on that first day, the image data are copied to a 2.3 GB drive associated with the review station in the reading room and deleted from the host computer disk where they will reside for 30 days at which time they are deleted. In this manner, all of the PET image data can be reviewed from hard disk for thirty days post-acquisition. To review studies older than thirty days, they must be de-archived from the optical disks and placed back onto the system. There are two optical disk drives on the system: one in the control area for

archiving and one in the reading room for de-archiving. In the event that one of the optical disk drives fails, the other can be used for both archiving and de-archiving. In addition to the image archive described above, the system and user-generated software are backed up weekly onto helical tape.

C. Data Base Description

Although a skeletal database was included with the Siemens ECAT software, it lacked flexibility and expandability. We required the ability to record detailed patient information and to easily generate comprehensive reports in order to support both our research and clinical efforts. In addition, we felt the need to select a database product that was supported on all three of our hardware platforms: Sun, PC, and Macintosh. The above requirements led to our choice of dBASE IV. We currently have a hierarchically designed database with comprehensive support for table lookups to aid data entry. The following is a rough sketch of our current database:

PATIENT INFO

MAIN KEY: Patient Medical Record Number

DESCRIPTION: A record consists of static patient demographic information such as medical record number, name, race, and date of birth.

VISIT INFO

MAIN KEY: Patient Medical Record Number + Visit Date

DESCRIPTION: A record contains information that is true for the day that the patient is seen. Variable patient demographic data such as age, height, and weight is included as well as referring physician, reason for visit and/or research protocol. Also recorded is a paragraph describing the conclusions of the radiologist reading the scan(s), and a result code that summarizes the conclusions ("definitely normal", "probably normal", ... "definitely abnormal"). There is the facility to enter variable amounts of data describing patient history and current medications.

STUDY INFO

MAIN KEY: Patient Medical Record Number + Visit Date

SECONDARY KEY: Study Number - a unique scan number generated by the ECAT software.

DESCRIPTION: a record contains information particular to a particular scan acquired during the patient's visit to the PET Center. A patient may have several study records for a given visit, each describing a single scan. Data recorded includes the time of injection of radiotracer and the radiotracer batch number. There is also a field which describes the number of the optical disk on which the scan data is archived. This provides a directory to the library of optical disks.

III. Current Issues

A. Software Development

In order to rely on the computer display for diagnosis, the software provided with the scanner had to be enhanced. First, many of the studies performed in the Center have associated correlative imaging data such as MR, CT or SPECT. Since the Siemens ECAT software could easily handle all the pertinent matrix sizes and was to be the basis of further software development, it made sense to convert these correlative image files to ECAT format. At present, we have utilities that will convert GE CT and MR files, Trionix SPECT files, Siemens ICON files and Interfile into ECAT format.

It was also necessary to enhance the provided display software. Due to the nature of our images, it is sometimes difficult to determine the placement of lesions in an anatomical context. By using maximum pixel reprojection (Wallis 1990), 3D images of the scanned volume can be generated. A series of such images can be generated and displayed in cine mode to give the user a 3D gestalt of the volume of interest. This display has been incorporated into a 3 view display of the transverse, sagittal and coronal images. A location can be selected on any of the images (including the 3D images) with the cursor and the corresponding views going through that same location are selected.

As mentioned above, there are often imaging correlates to our PET studies from SPECT, CT or MRI. The ability to "register" the image sets is extremely important in these cases. We have developed methods using or a surface matching technique (Pelizzari 1989). Once the images are registered, it is important to have a tool specifically designed to display and analyze registered image sets so the user can most easily and accurately glean the diagnostically relevant information available from the studies. We have developed two "mirrored" displays for this purpose. The first brings up a single view (say transverse) of the registered image sets side-by-side. The user can then page through the entire set of registered images. The cursor can be placed on one of the images and it is mirrored on the other registered images. For analysis, a region of interest (ROI) drawn on one of the images is mirrored onto the others and the quantitative data from all of the registered images can be obtained for that ROI. In the second version of this program, transverse, sagittal and coronal images are displayed for all registered image sets. We have found these tools to be of substantial value in the review of these registered image sets.

B. Reliability

Many radiology and nuclear medicine divisions boast about having the capacity to be all digital but most maintain the practice of printing a film as backup for each study. When a division decides to no longer print film on a routine basis, the requirements for reliability change dramatically as has been previously discussed. This affects the working of the network, and the manner in which studies are archived. The P.E.T. Center network provides our users with an easy-to-use, efficient and convenient means of accessing the data. However, the daily number one priority is the acquisition of that day's studies

and their review. For this reason, we have designed our network and distributed archive such that we can continue to acquire data from the PET scanner (or the SPECT scanner) even if the network is down. For the PET scanner, this requires connecting the PET scanner host Sun workstation to the MR 68000 acquisition processor by a backup thin-wire Ethernet. At this point, the data can be acquired and reconstructed and reviewed at the host workstation.

IV. Future Directions

As requests for new studies increases and the archive of old studies grows, the required storage capacity for our system continues to grow. As described, our current system has a 2.3 GB drive for long term (30 day) online storage. This archive is consistently in excess of 95% full. It is expected that this will need to be increased in the near future. We also plan to add new review and processing workstations to our system to meet the needs of our investigators. In addition, as the locations of our investigators extend beyond the local campus, access to the data must be provided at these locations. Two such locations (the Friedberg Primate Center and the Piedmont Triad Research Center located 8 and 2 miles from the main campus, respectively) will be connected to the main campus Ethernet backbone through T1 lines and eventually through ATM. We will also continue to enhance the display software to meet the needs of our collaborators and investigators.

V. Summary

We have designed and maintained a filmless, all-digital PET Center for over two years. This network contains Sun workstations, PCs and Macintoshes and all of these can share data. In addition, we are connected to the rest of the Radiology Department and routinely retrieve correlative image data (MR, CT and SPECT) from these sites. The totally filmless design has placed added requirements for reliability both in terms of the operation of the network and the archive. Our experience and the experience of other limited filmless divisions such as ours provides essential data in the design and understanding of the larger filmless radiology departments.

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SESSION 2

Image Processing

Chair: David W. Piraino

Early Detection and Enhancement of Cancerous Changes in Mammograms Using Digital Image Processing

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I. INTRODUCTION

Early detection of breast cancer is the key to successful treatment, low cost treatment, and reduction of mortality. Routine mammograms are recommended for a large percentage of the female population as the most reliable detection method. Massive screenings across the population are still not a reality because there are a number of problems encountered in mammogram screenings. One of the major problems is the high cost of the procedure. Significant part of this cost is associated with mammogram readings, which are performed by highly skilled experts. Additional problems are related to the inconsistency in readings of human experts due to fatigue. Recently, researchers have concentrated on automated mammogram analysis as a viable solution to these problems. The research efforts primarily concentrate on specific subproblems, emphasizing mammogram enhancement, detection of microcalcifications, and detection of particular classes of tumors (Stewart et al.¹ review related approaches).

The work described in this paper concentrates on digital image processing methods which autonomously single out mammograms that exhibit early cancerous changes. These methods are envisioned as a computer-based aid for mammogram screening with the objective of drawing the attention of medical experts to particular regions in mammograms and of helping to establish the correct diagnosis. The methods perform two types of tasks: (1) mammogram segmentation with objective of finding suspicious regions and (2) enhancement of detected regions. The paper describes the essence of the segmentation method and its two versions, the first version is aimed at the detection of microcalcifications and the second at detection of masses. The two versions were evaluated using synthetically generated objects superimposed on normal mammograms and using mammogram images for which the corresponding truth images were generated by medical experts. The objective of the first evaluation was to precisely determine the method's capabilities and its sensitivity to object size, shape, and contrast. The objective of the second evaluation was to establish the method's usefulness in helping medical experts to establish the diagnosis. The emphasis in this paper is on evaluation using mammograms and corresponding truth images.

II. MAMMOGRAM SEGMENTATION

The objectives of our algorithms are to pre-screen mammograms and separate

them into two groups, those containing potential cancerous signs, and those that contain no suspicious signs. The mammograms in the first group are segmented into “suspicious regions” and normal tissue. The segmentation algorithm described in this paper is based on *the fuzzy pyramid linking method*². The essence of this method is multiresolution image analysis that allows, similarly to human perception, first comprehension of the global structure of a mammogram, followed by a search for fine detail. The multiresolution pyramid is created by using the original image I_0 of dimensions $2^n \times 2^n$ as the base of the pyramid. Each subsequent level of the pyramid, $I_1 \dots I_n$, is a square array which is half the dimensions of its predecessor. These arrays are lower resolution representations of the original image. The top level I_n of the pyramid is a 1×1 array. An element (node) of the array I_l ($l > 0$) is obtained by a Gaussian weighted averaging of the I_{l-1} nodes within a $k \times k$ neighborhood. The nodes belonging to a given level of the pyramid are connected with nodes at adjacent levels using links. The pyramid is redefined iteratively and new links are determined. We use links such that a son node is linked to all four candidate father nodes. In the proposed algorithm, the following variables are defined for the linking and ensuing iterative pyramid redefining process:

- $t_l(i, j)$: the *local image property* (in this paper intensity);
- $p_l(i, j)$: the *pointer* to the node's father one level above having the maximum link strength, hereafter referred to as *the maximum link*;
- $s_l(i, j)$: the *strength value of the link* between the father and the son nodes.

The iterations proceed in the following manner:

1. For level $l = 0$ set

$$s_0(i, j) = 1 \quad \text{and} \quad t_0(i, j) = I_0(i, j).$$

2. For each level l from 1 to $n - 1$ set

$$s_l(i, j) = \sum_{i'j'} s_{l-1}(i', j') \phi_{i,j,i',j'},$$

where $\phi_{i,j,i',j'}$ denotes the strength of the link between the node (i, j) at level l and its son (i', j') at level $l - 1$,

and

$$t_l(i, j) = \sum_{i'j'} t_{l-1}(i', j') \phi_{i,j,i',j'},$$

with summations performed over all sons of the node.

3. For each node at level l , for $0 \leq l < n - 2$, the pointer $p_l(i, j)$ points to the father node at level $l + 1$ that has the maximum link strength among

the four candidate father nodes. If two or more parents have the same link strength, a link is chosen randomly; however, if either link existed in the previous iteration, the link remains unchanged.

4. Once the links have propagated to the top of the pyramid the value of every node, except those at level 0, is recomputed in the following manner:

$$I_l(i, j) = t_l(i, j) / s_l(i, j) \quad \text{for } s_l(i, j) > 0.$$

5. If no link is reassigned during the current iteration, it is assumed that a steady state has been reached. If any number of links have been reassigned during the current iteration, the procedure is repeated starting from Step 2.

Upon reaching steady state, image segmentation is achieved in one top-down pass beginning from level $n - 1$. In this pass, a son node at level l is replaced by the father node pointed to by $p_l(i, j)$. The proposed algorithm limits the propagation of the links for specific nodes by requiring that the links between the son and father nodes (pointed by $p_l(i, j)$) exceed a specified threshold τ .

The choice of the function ϕ , representing the strength of the link, determines the flexibility of the pyramid segmentation. In this work, the strength of the link between nodes (i, j) and (i', j') is modeled by

$$\phi_{i,j,i',j'}(u; \alpha, \beta, \gamma) = 1 - S(u; \alpha, \beta, \gamma), \quad (1)$$

where

$$S(u; \alpha, \beta, \gamma) = \begin{cases} 0 & \text{for } u \leq \alpha \\ 2 \left(\frac{u - \alpha}{\gamma - \alpha} \right)^2 & \text{for } \alpha \leq u \leq \beta \\ 1 - 2 \left(\frac{u - \gamma}{\gamma - \alpha} \right)^2 & \text{for } \beta \leq u \leq \gamma \\ 1 & \text{for } u \geq \gamma \end{cases} \quad (2)$$

and $u = |I_l(i, j) - I_{l-1}(i', j')|$. The parameters α and γ determine the shape of the function, and $\beta = \frac{\alpha + \gamma}{2}$.

Presently we are using two versions of the algorithm; the first version aims at detection of microcalcifications and the second aims at detection of masses. The two versions differ in the way the segmented image is generated and in selection of parameter τ ; in both cases $\alpha = 5$ and $\gamma = \text{image mean}$.

- *Detection of microcalcifications* The segmented image contains only pixels whose links have not propagated from the top of pyramid when choosing small values for τ . The corresponding pixels are either small objects or edges, and the two groups of pixels can be easily differentiated since the groups corresponding to edge pixels increase in size when τ is increased, while small objects retain their shape and size.

- *Detection of masses* The segmented image consists of pixels which have propagated from the top of the pyramid when choosing a small threshold value.

III. MAMMOGRAM ENHANCEMENT

The objectives of enhancement algorithms are to make mammograms more suitable for examination by medical experts or to allow more detailed segmentation by the fuzzy linking pyramid algorithm. Since the cancerous changes are associated primarily with high intensities, our objective is to enhance intensity differences among the high intensities and suppress the low intensities. The partial list of the techniques that are presently under testing to achieve this objective is as follows:

- *Contrast stretching*, i.e., increasing the dynamic range of intensities.
- *Compression of dynamic range*, i.e., bringing out the details that are not visible due to the wide range of intensities present in an image.
- *Histogram manipulations*, i.e., bringing out important intensity ranges, using methods of local and global equalization.
- *Pseudo-coloring*, i.e., assigning a specific color to each intensity so that even small intensity differences become visible.

All of these techniques are successful in bringing out details in some types of mammograms. Particularly successful are the histogram equalization methods applied to regions of the images labeled to be homogeneous by the segmentation method. The subsequent segmentation of the enhanced regions brings out details, such as microcalcifications that could not be detected initially.

IV. RESULTS AND DISCUSSION

The performance of the methods was evaluated in two ways. First, the performance was evaluated using synthetically generated objects superimposed on normal mammograms. This allowed us to measure objectively the capabilities of the method to detect objects of low contrast and small size. Next, the performance was evaluated on mammograms for which the truth images were generated by human experts. In both cases the primary concern was that the method always detects potential cancerous signs considered. The secondary concern was that the method minimizes false alarms. The generation of synthetic images and method evaluation is detailed in [2]. In the following we summarize performance on real images.

The performance of the method regarding microcalcification detection was evaluated on two sets of images. The first set consisted of low resolution mammograms and contained 17 examples of microcalcifications and 50 normal mammograms. Initially, the method has detected the presence of microcalcifications in

13 images correctly. Microcalcifications were detected in the remaining 4 images after enhancement, Figure 1 shows one of these images. The second set of mammograms consisted of 10 images digitized at high resolution (pixel size .1 mm) and the microcalcifications were correctly detected in all images. However, in this case false positives were also detected in the same mammograms; no false positives were detected in low resolution imagery. Detection of masses was evaluated on 12 abnormal cases and 50 normal mammograms. The masses were precisely detected in 8 cases initially and in the remaining 4 cases after enhancement. The method has detected false positives in 5 out of 50 normal mammograms. An example of the segmented mammogram is shown in Figure 1, together with the results of an enhancement algorithm applied to detected regions.

The performance evaluation indicates that the method has the potential to be used in massive mammogram screenings. Generally, the method is capable of detecting changes in mammograms, when they are visually present. Moreover, a very low rate of false alarms is reported by this method. Presently, we are evaluating the impact of various enhancement methods on the fuzzy linking algorithm. Appropriate enhancement methods can significantly increase the detection rate of true positives as already indicated by our preliminary results, where the detection rate improves after local enhancement.

Acknowledgement

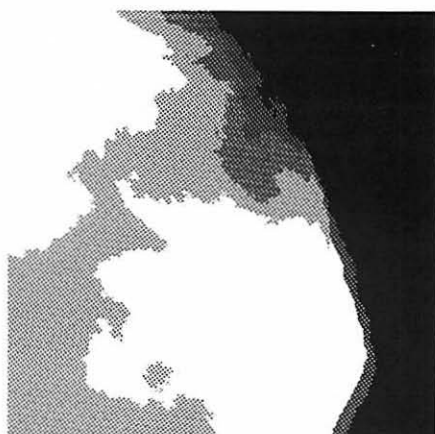
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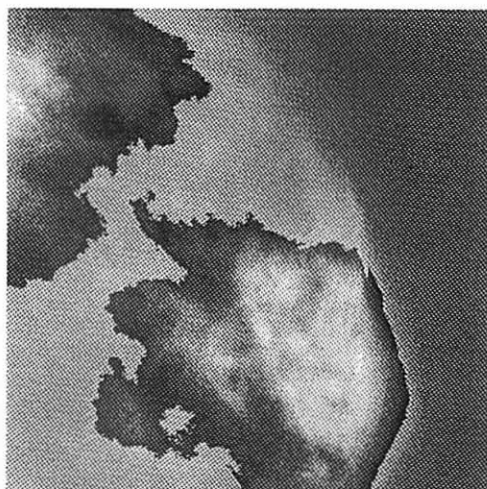
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(a)



(b)



(c)

Figure 1: An example of mammogram analysis: (a)original mammogram, (b)initial output of the fuzzy linking pyramid-version detecting masses, (c)enhancement of the two bright regions detected in (b)—each region is independently scaled 0 – 255, and small intensity differences are more obvious.

An Algorithm for Detection of Masses, Skin Contours, and Enhancement of Microcalcifications in Mammograms

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Abstract

An algorithm for early detection of breast cancer, which combines three criteria of malignancy, is presented. The proposed technique detects a possible mass, the presence of microcalcifications, and it examines the contour of the skin to detect retraction or thickening. The procedure, which combines techniques of image enhancement and feature extraction, is tested with a series of 32 mammograms. A success rate of 100% of the exemplars studied is shown for the detection of masses and enhancement of microcalcifications, and a success rate of 88% is shown for the detection of the skin.

1. Introduction

Early detection of breast cancer has been the primary goal for many researchers in the past few years. Preventive checkups are carried out throughout the world with the intention of cancer prevention. Statistics show that breast cancer is the most common cancer among women. It is estimated that in 1993 there were 182,000 new cases of breast cancer, and 46,000 women died from this disease [1]. Considerable attention is given to breast cancer because of the potential to reduce the mortality rate by participating in screening programs [2]. Mammography is the only method capable of screening non-palpable breast cancer [3], and extensive research is carried out to improve the quality of the mammograms for better feature identification. Even though mammography is currently the best method for breast cancer detection, 10% to 30% of women who undergo mammography, and who have breast cancer, have negative mammograms [4]. One of the reasons why this might happen is the poor quality of the obtained images.

Many attempts have been carried out with the intention of enhancement as well as detection of cancerous masses in mammograms. Brzakovic D., Luo, and Brzakovic P. [5] describe a system for the detection of tumors in digitized mammograms. The system first finds the region of interest in an image, and then analyses this region to determine if there is a tumor. The algorithm used here for the analysis of the images is based on fuzzy pyramid linking for image segmentation. An adapting method for enhancing mammograms is described by Morrow and Paranjape [6]. This method uses each pixel in the image as a seed to grow a region. The contrast of each region is then calculated and enhanced. Bankman et al [7] describes an algorithm for detecting clusters of microcalcifications based on the contour map of mammograms. The algorithm extracts five features from the microcalcifications, which are then used to classify the regions.

Even though the previous approaches showed relative success, a more consistent classification method must use primary as well as secondary signs of cancer. Primary signs of malignancy are a mass and/or microcalcifications. Secondary signs include, among others, skin thickening or retraction associated with an underlying carcinoma [8].

This paper describes an algorithm for the detection of breast cancer which combines

three criteria of malignancy: the presence of a mass, the presence of microcalcifications, and the analysis of the contour of the skin to identify skin retraction or thickening associated with the possible carcinoma.

Figure 1 describes the approach which combines three processing stages: the detection of a mass, the detection of the contour of the skin, and the detection and enhancement of microcalcifications.

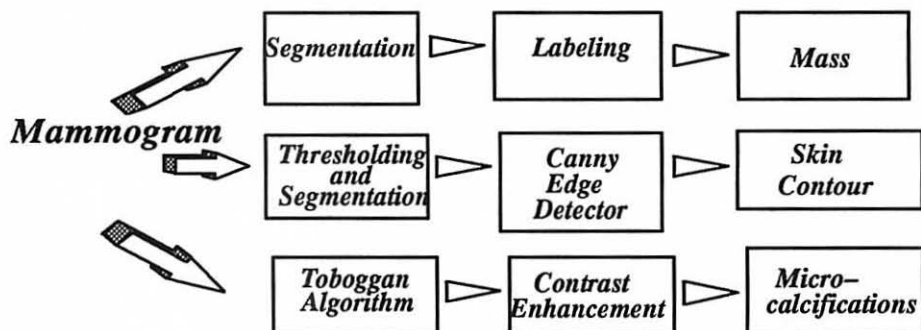


Figure 1: Chart for Automated Detection of Masses, Skin Contour, and Enhancement of Microcalcifications in Mammographic Images.

2. Detection of Masses

To perform the segmentation process, the histogram of the image is first constructed as shown in figure 2.

By assuming that all the gray levels for that particular image form one set of values, such as $S1$, we can find a median $m1$ for this set in such a way that half of the values of $S1$ are less than $m1$ and half of the values are greater than $m1$. The numerical value given to the set $S1$ is given by $S1 = (P0 + P1 + P2 + \dots + P_{n-1}) / n$, where $P0 \dots P_{n-1}$ represent the pixel values, and n is the total number of pixels.

Two new sets are now created, $S2$ and $S3$. Set $S2$ is formed by the histogram's lower intensities, or the intensities lower than the median $m1$, and set $S3$ is formed by the upper intensities of the histogram, or the intensities greater than $m1$.

We can also say that the numerical values for $S2$ and $S3$ are given by

$$S2 = \frac{\sum_r P(i < m1)}{r} \quad S3 = \frac{\sum_s P(i > m1)}{s}$$

where $P(i < m1)$ are all pixel values with intensities less than the median $m1$, $P(i > m1)$ are all the pixel values with intensities greater than median $m1$, r is the number of total pixels with $(i < m1)$ and s is the number of total pixels with $(i > m1)$ [9].

A median $m2$ can now be found for set $S2$ in such a way that half of the intensity values of $S2$ are less than $m2$ and the other half are greater than $m2$. Similarly, we can find a median $m3$ for set $S3$, which will also divide set $S3$ in two halves. Medians $m2$ and $m3$ are used as the dividing borders for the formation of four new sets: $S4$, $S5$, $S6$, and $S7$.

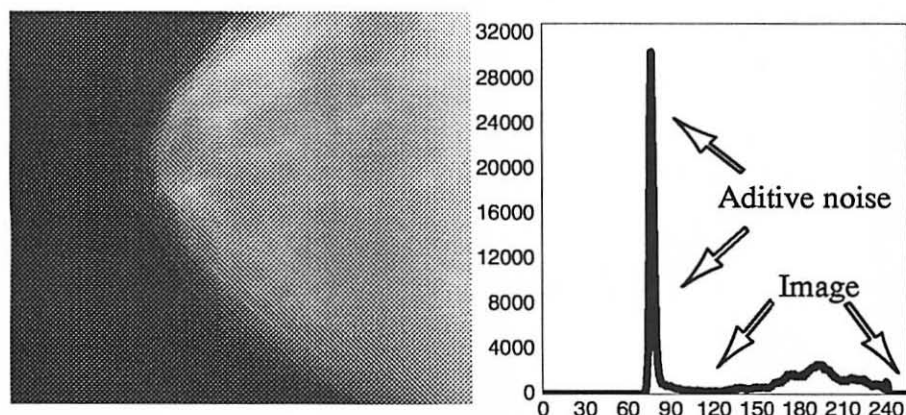


Figure 2: (a)Sample original mammogram, (b)Sample Histogram

Sets S_4 and S_5 are obtained from previous set S_2 , and sets S_6 and S_7 are obtained from previous set S_3 . The numerical values for the four new sets are given by

$$S_4 = \frac{\sum_{i} P \subset S_2 (i < m_2)}{t} \quad S_5 = \frac{\sum_{u} P \subset S_2 (i > m_2)}{u} \quad S_6 = \frac{\sum_{v} P \subset S_3 (i < m_3)}{v}$$

where t is the total number of pixels with intensities less than m_2 in set S_2 , u is the total number of pixels with intensities greater than m_2 in set S_2 , v is the total number of pixels with intensities less than m_3 in set S_3 , and w is the total number of pixels with intensities greater than m_3 in set S_3 .

This process of separating the original set of gray levels into sub-sets is repeated until the number of sets requested by the user is reached. After all the sub-sets are found, we can form a look up table mapping the original intensities of each pixel with the new pertaining intensity value. It is important to experiment with several images when applying this process of gray level reduction to obtain a standard reduction level. If the histogram of the image is divided into a small amount of sub-levels, then it would not be possible to completely separate the detected mass from surrounding tissue. On the other hand, if we divide the histogram into too many sub-sets, some of the area of interest might be lost in the process. In our work we found a sub-level of eight to be the standard level of division. When seven (or less) levels were used, it was not possible to completely separate the detected mass from its surroundings. If a value greater than eight was used, some of the intensities which belonged to the detected mass were lost.

Figure 3(a) shows an example of an original mammogram in which there is a visible mass. When six sub-sets are used for segmentation, Figure 3(b), the mass is not completely separated from other areas in the mammogram. On the other hand, when ten sub-sets are used, Figure 3(c), some of the mass tissue is lost. Figure 3(d) shows the best level for segmentation, or a level of 8.

The next step after segmentation is classification. By labeling the image, it is possible to separate the mass from the rest of the breast tissue. Labeling was achieved by calcu-

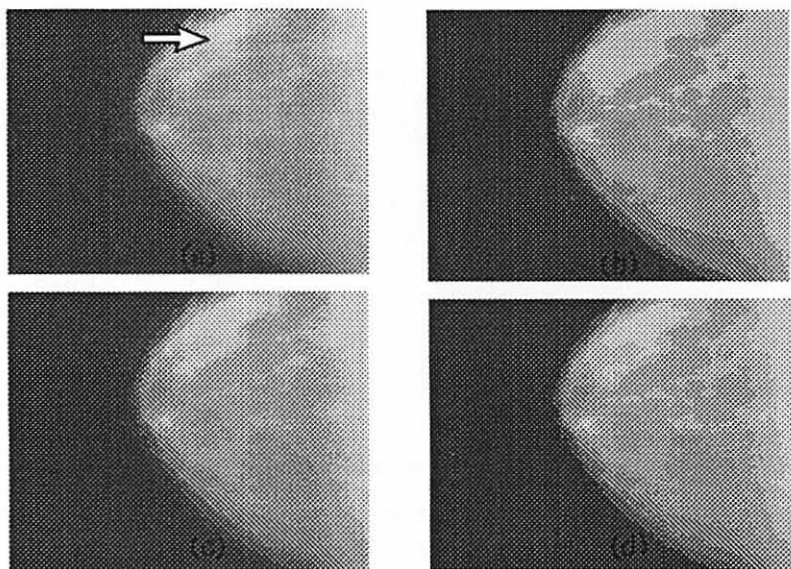


Figure 3: (a)Original Mammogram with arrow pointing to cancerous mass, (b)Image segmented with level 6, (c) Image segmented with level 10, (d) Image segmented with level 8.

lating the likelihood distance among pixels and linking pixels at acceptable distances from each other using a four connectivity criteria. The Euclidean distance was used for distance computations [10]. Figure 4 shows the previous image segmented with level 8 after labeling.

Labeling depends strictly on the previous segmentation process. If, during segmentation, the detected mass is not completely separated from surrounding tissue, labeling will not differentiate mass pixels from surrounding pixels.

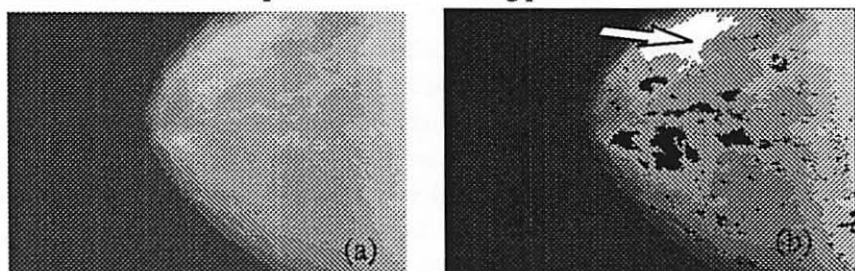


Figure 4: (a)Segmented image with level 8 (b)Same image after labeling. Arrow shows detected mass.

2.Detection of Skin

It is difficult to correctly detect the skin in mammograms since it has low contrast and tends to blend with the background. Several thresholding preprocessing steps are required to exclude all the areas of the mammogram with high intensities. Since the intensity for skin areas in all mammograms ranged from gray levels 65 through 95, all other

values were thresholded for our analysis. The heart of the skin detection process is the use of the Canny edge detector, which is an optimal line finding algorithm [11].

There are two common criteria relevant to edge detection performance. The first is the prevention of missing an edge in the image, and that any edge found is not a suspicious response, commonly known as low error rate [11]. This is defined as the output signal-to-noise ratio, which is given by

$$SNR = \frac{\left| \int_{-w}^{+w} G(-x) f(x) dx \right|}{n_0 \sqrt{\int_{-w}^{+w} f^2(x) dx}} = \frac{H_g}{H_n}$$

where $G(x)$ is the notation for the edge, $f(x)$ is the notation for the filter, H_g is the convolution integral showing the response of the filter to the edge, and H_n is the root-mean-squared response to the noise $n(x)$.

The second criterion is the correct localization of edge points, thus minimizing the distance between the points marked by the detector and the center of the true edge [11]. For localization, the reciprocal of the root-mean-squared distance of the marked edge from the center of the true edge is used, which increases as localization improves, and is given by

$$Localization = \frac{\left| \int_{-w}^{+w} G'(-x) f'(x) dx \right|}{n_0 \sqrt{\int_{-w}^{+w} f'^2(x) dx}}$$

where $G(x)$ is the notation for the edge, and $f(x)$ is the notation for the filter.

A third criterion is added to the Canny algorithm, which ensures that the detector has only one response to a single edge. Thus, the response to the edge detector will guarantee a response to a global maxima in the region of an edge instead of finding local maxima in that particular region [11].

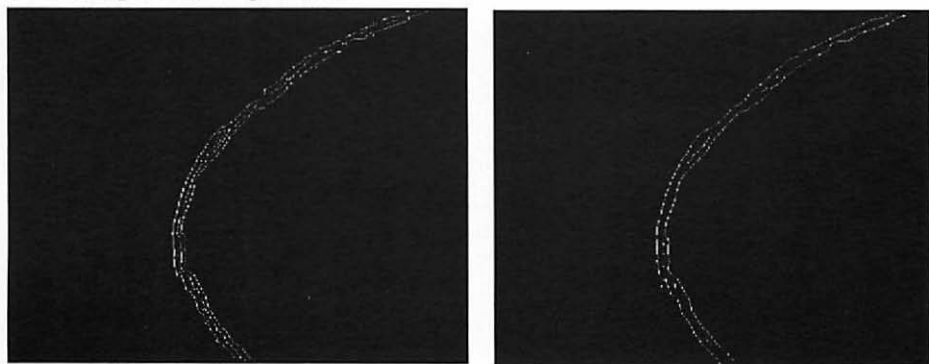


Figure 5: Mammogram after skin detection with (a) $\sigma = 1$, (b) $\sigma = 3$. The Canny edge detection algorithm utilizes a Gaussian mask over a window of the

image to compute edges. A two-dimensional Gaussian function G is given by

$$G = \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

where σ , or sigma, is used as the detection function.

By changing the value of sigma, we can increase the edges captured by the edge detector. That is, when a lower value for sigma is used the algorithm becomes more sensitive to edges. When a greater value for sigma is used, the edge detector is less sensitive to edges. Figure 5 shows a comparison between varying sigmas when detecting skin contours.

In figure 5(a), a value of 1 was used for sigma. It can be seen how much sensitive the edge detector is in contrast with figure 5(b), where sigma has a value of 3.

3.Enhancement of Microcalcifications

Microcalcifications were enhanced using the Toboggan Contrast Enhancement algorithm, which is a non-iterative, single-parameter, linear execution time method for selectively augmenting the contrast of multi-spectral images of arbitrary dimensionality [12].

The Toboggan algorithm applies Toboggan enhancement to the image, followed by contrast segmentation, which yields as result an image equal in quality to that of an optimal region growing method.

By calculating a measure of discontinuity of the image at a certain pixel, we can slide "downhill" on the discontinuity surface until reaching a pixel with is a local minimum in discontinuity [12]. Thus, the enhanced image is given by $T(p) = I(l(p))$, where p is the starting pixel, $l(p)$ is the pixel which is the local minimum, I symbolizes the image, and T is the enhanced image.

A spatial mask is implemented for the calculation of the discontinuity measures, which size affects directly the enhancement, or growing, of each pixel. As it can be seen in Figure 6, microcalcifications are greatly enhanced using a mask of size 22 for the discontinuity measures and Toboggan enhancement. However, if masks of greater sizes are used, other high intensity areas of the mammogram, such as small glandular regions, will also grow thus deteriorating the contrast between calcification and glandular tissue.

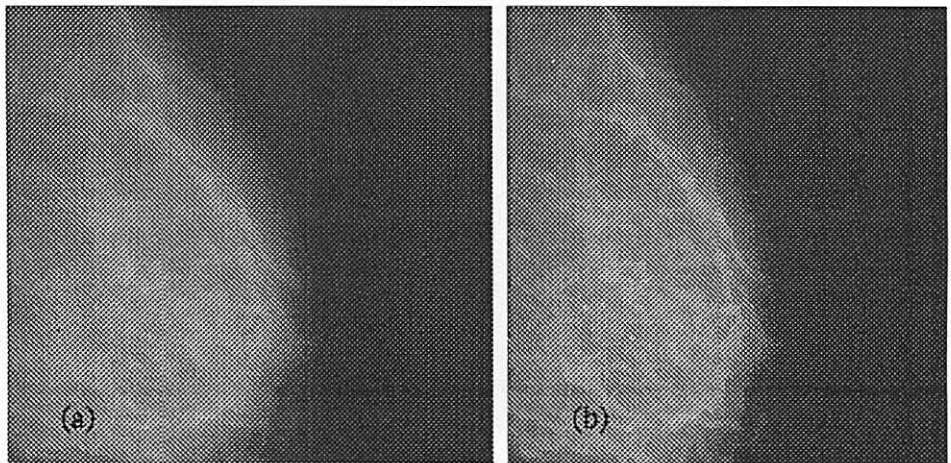


Figure 6: (a)Original Mammogram w/microcalcifications, (b) After Enhancement.

4.Results

A series of 32 mammograms were analyzed to evaluate the performance of the algorithm. From the 32 mammograms, 16 had at least one visible mass, 16 were normal, and 15 had some microcalcifications.

The evaluation of the algorithm was difficult because there is no standard for its performance. For this reason, parts of its evaluation was done visually, giving a qualitative judgment on the result by experienced radiologists. Such a case is applicable for the detection and enhancement of microcalcifications and for the detection of the contour of the skin. Classification of the skin and enhancement of microcalcifications in the segmented image were compared to the original mammogram and judged in appearance by radiologists. All microcalcifications were enhanced, even some not easily visible by the human eye, yielding a success rate of 100% for the enhancement of microcalcifications. Seven out of 32 skin contours were not identifiable due to the low contrast between the skin area and the background noise of the image, giving a success rate of 88% for the detection of the skin contours.

mamm#	mass area	breast area	%of mass
<i>can1.dat</i>	5,836	16,371	36%
<i>can2.dat</i>	16,101	158,219	10%
<i>can3.dat</i>	6,180	152,540	4.05%
<i>can4.dat</i>	3,238	83,757	3.87%
<i>can5.dat</i>	5,463	130,168	4.20%
<i>can6.dat</i>	5,194	120,001	4.33%
<i>can7.dat</i>	15,706	184,024	8.53%
<i>can8.dat</i>	11,655	156,778	7.43%
<i>can9.dat</i>	8,017	151,312	5.30%
<i>can10.dat</i>	7,518	163,858	4.59%
<i>can11.dat</i>	5,352	134,963	3.97%
<i>can12.dat</i>	5,950	118,497	5.02%
<i>can13.dat</i>	2,918	199,052	1.47%
<i>can14.dat</i>	6,573	121,078	5.43%
<i>cyst1.dat</i>	3,922	131,811	2.98%
<i>cyst2.dat</i>	4,802	121,384	3.96%

Table 2: Areas of detected masses (in pixels).

The algorithm identified all visible masses in the mammograms. The approximate area for each detected mass was found to give an estimate of its size in contrast with the size of the entire breast. This was done by thresholding the noise in the image, based on histogram specifications, calculating the area of the detected mass and dividing it by the area

of the entire breast. Table 2 shows the approximate areas found for each mass.



Figure 6: (a)Image after labeling, (b)After skin is detected, (d)After microcalcifications are enhanced. The values in the first column of Table 2 represent the area of the detected masses in each image, while the values in the second column represent the area of the breast tissue, excluding background noise. The last column gives an idea of the size of the detected mass in contrast with the size of the image. For example, a mass is detected in the mammogram labelled *can3.dat* which occupies 4.05% of the total breast tissue. An original example and its results to each step of the algorithm is shown in Figure 6.

5. Conclusion

An algorithm for the detection of masses, skin contours, and enhancement of microcalcifications has been proposed. This method was designed with the purpose of combining primary as well as secondary signs of malignancy for better detection of breast cancer. It was shown how the results of the algorithm can benefit radiologists when reading mammograms, since enhancement preprocessing stages are a crucial part for this technique. Visual evaluation of the algorithm was performed by experienced radiologists and approved in terms of enhancement and detection.

Acknowledgment

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Diagnostic Ability of Computer Recreated Images of Pathological Lesions of the Alimentary System

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Objective:

It is easier to diagnose a lesion when observed macroscopically. Such option also helps to measure the size and extent of the pathology to decide the course of the surgical intervention. Because of these advantages' modalities like endoscopy gathered immense popularity in viewing luminal organs such as the gastrointestinal tract. Our experiment endeavors to offer such facilities by recreating 3D images of the pathological lesions of the gastrointestinal tract from CT data and in addition display the images in a flat plane to enhance the diagnostic ability.

Methods:

We selected eleven patients with pathological lesions in different parts of the alimentary tract; 3 cases were of the stomach; 3 of rectum and 6 were of the sigmoid colon. We chose lesions of variable size and configurations to test the reconstructive capability of the system and to observe the influence on the diagnosis. We scanned the patients according to the site of involvement using a Helical CT scanner with a slice thickness varying from 2 to 5 millimeter; transferred the scanned data to a SUN SPARC graphics workstation through the ethernet network to reconstruct 3D images from the helical data with the help of CEMAX graphical program. Initially, the images were viewed through the view module of the software to observe the extent of the disease along the lumen of the organ. Next, a region of interest was defined and the number of slices was selected depending on the extent of the pathology. Since we observed the results of the alimentary tract, the tissue classification had to be customized to obtain the optimum image. The classification was based on the air-soft tissue interface, vessels and bone density. The bone density was completely deselected to display the soft tissue structures only. After the final classification, the axial images were rendered to create the 3D image. For each case, we created a minimum of three 3D images; one image consisting of the whole organ and the other two was the halves of the longitudinal cut section. The images were then displayed and viewed from different angles, then saved as PICT files and transferred to a Macintosh computer. In the Macintosh we used the Photoshop software to view the images. The flat plane profile was created by placing the cut sections side by side on a canvas of the software. It was then printed in plain paper

using the Canon color copier. A simulation of a surgical incision on the wall of the tract was made by the two halves of the 3D image simulating the two flaps of the gut. The gap between the flaps were widened by increasing the viewing angle and this simulated as if the two flaps had been pulled apart till the whole lesion was exposed in a flat plane. This preserved the elevations and depressions of the lesion but provided better perception of the pathology in relation to the wall and the lumen interior. The tissue classification module of the program aided to enhance the tissue characteristics of the lesion and distinguish the different tissue type. The coloring tool helped to focus the diagnostician's attention to the lesion.

Discussion.

Since the alimentary tract is a hollow tube so far the existing modalities have provided axial views of the interior or 3D views from each end of the tract. With the computer reconstructed images we could in addition, recreate 3D images of the lesions; reorient the planes of observation and view the images in a frontal plane projection. The cases of the stomach were of type IIc like advanced gastric cancer (n=1) and submucosal tumors (n=2). Submucosal tumors were easier to identify because of the induration on the stomach wall. One of these were histopathologically proved to be of the leiomyoma type. Three dimension had no advantage in detecting the other lesion of early gastric cancer (type IIb + IIc) and it was the same in the case of leiomyoma. This type of lesion is also not detected in upper GI series. It is possibly due to the absence of any elevation or excavation on the mucosal surface that leads to an assumption of a normal mucosa. The rectal cases were of Borrmann type II rectal cancer (n=2) and rectal polyp (n=1). In cancer of the colon (n=5) the extension was easily identified macroscopically and hence through the 3D images. But at present it is not possible to differentiate submucosal penetration for which we had to revert back to the axial images of the CT. It was also the same with the other cancer cases of the sigmoid colon; consisting of applecore lesion (n=1), and Borrmann type II (n=2) and Borrmann type I (n=1) pathologies. This indicated that it would be better to evaluate 3D images with conventional CT images and the composite may provide additional information in specific cases. The other case (n=1) was of a polyp. Identifications of polyps on 3D images were efficient as small polyps could be appreciated easily. The disadvantages include the tissue dropouts on recreated images because of the complexity of the threshold adjustment and the incapability of the system to demonstrate the subtle changes like the IIb type of early gastric cancer.

Conclusion:

The new technique of viewing the lumen of the tract in a three dimensional flat plane has provided us with a better and more accurate tool in defining lesions of the alimentary tract.

Image Enhancement: Effects for Detection of Gastric Carcinoma on Radiographs

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1. Introduction

Malignant neoplasms are leading causes of death in Japan. Detection of the tumors in their early developing stage is indispensable for improvement of the curable rates of treatment. Regular health checking is believed to be useful for early detection. The examinees have been checked at almost the same period in each year. The procedure of health checking is carefully performed in comparison with past examination records. The accumulated data are also indispensable ones for explication of process from healthy to pathologic condition.

Digital radiography has allowed new advances in gastrointestinal radiology. Image processing techniques have been studied in radiographs of the gastric cancer cases that were proven at surgery. The goal of this project is to improve the detection rate of early gastric cancer by using digital image enhancement.

2. Materials and Methods

(1) System Configuration

In digitalization and processing of the clinical radiographs, EXCEL system is used (Fig 1). The EXCEL system is composed of CCD-TV camera using to input an image to 512 x 512 x 8bit, processing software, 512 x 512 black / white and color CRTs displaying the processed image, video imaging camera recording a hard copy and 5.25 inches in floppy disk storing images. The Display system for processed image s equips 512 x 512 color display, image scanner and 3.5 inches magneto-optical disk drive.

(2) Image Processing Methods

The techniques are divided into three categories : grey-scale processing, filtering, and algebraic manipulation. The first one is grey-scale transformation, which helps select a look-up table to be displayed on CRT. The second is Sobel

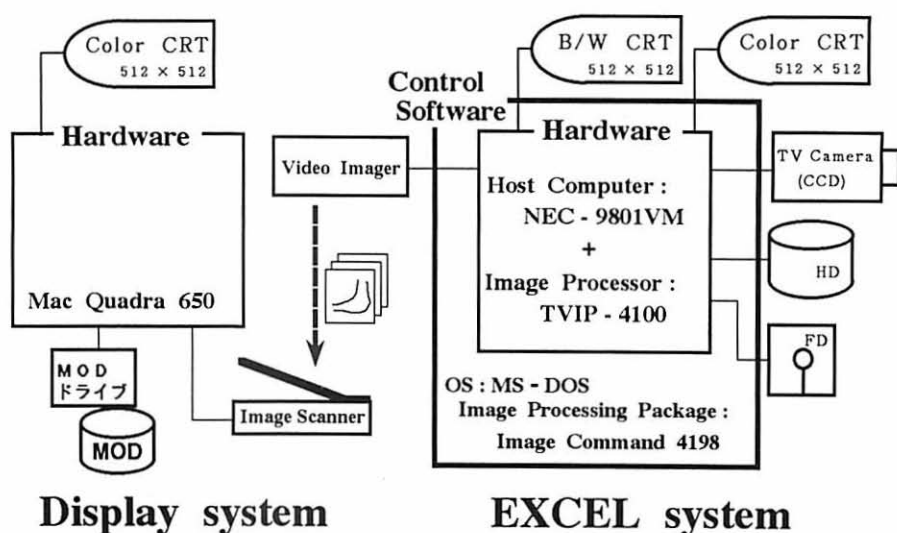


Fig. 1 System configuration of the research project.

operator which is one of the well-known edge enhancement filters. The third, unsharp masking is high-pass filtering with blurred or unsharp mask subtraction.

(3) Image Processing Procedures

Original radiographs were displayed on a viewbox for selection of two or three images that demonstrated malignant lesions most clearly. The images were processed by EXCEL system. With the CCD-TV camera (512×512), pixel size is equivalent to 0.3 to 0.6mm to a spot film size. A hard copy of the processed image was recorded on Konica medical imaging film new C (20.3×25.4cm) with the video-imaging camera.

(4) Material Radiographs

Gastrointestinal radiography was examined by a remote-controlled X-ray television set (Shimadzu MS-2 : roll film type with ten different spot sizes) with automatic exposure condition, Kodak X-Omatic regular screen, Konica new A regular type film, and 140% barium meal.

We selected 45 gastric cancer cases from the file. They have been examined by the radiological procedure in last 3 or 4 years before detection of the gastric cancer lesion. The lesions had been proven with pathologic studies. Case types were divided according to the classification of the Japan Gastrointestinal Endoscopy Society in the cases with early gastric cancer.

3. Results

(1) Image Processing

Both Sobel operator and high-pass filtering are indispensable techniques in retrospective follow-up studies on the same location as detected malignancy.

Each image processing method has its characteristics. The Sobel operator can enhance a linear or curved margin and suppress the remainder. It depicts a lesion on the margin of the stomach and excavated pattern on the mucosa. High-pass filtering method is superior in demonstration of texture pattern on the gastric mucosa. By stressing elevated and depressed lesions on the mucosa, superficial cancer extension is more conspicuous. It is superior to enhance a protruded pattern on the mucosa.

(2) Clinical Results

Tumor occurrences are roughly divided into four groups : (a) on the nonpathologic mucosa ; (b) on the abnormal mucosa; (c) near the gastric ulcer scar; and (d) progress from overlooked shallow lesions suggestive of malignancy (Table 1).

Table 1 Cancer development with type of gastric cancer.

	Early G. C.		Advanced G. C.
	Protruded	Flat & Depressed	
Nonpath .M.	3	4	1
Abnorm.M.	1	1 5	3
Gastric U.S.		1 6	1
Overlooked			1

Nonpath : Nonpathologic Abnorm : Abnormal
M : mucosa U.S. : ulcer scar G.C. : gastric cancer

(a) On the Nonpathologic Mucosa

We found 8 cases (18%). Sobel operator is beneficial to depict the changes.

(b) On the Abnormal Mucosa

In this group, early gastric cancer develops on the coarse or atrophic mucosa (Fig 2). 19 cases (42%) were found.

(c) Near the Gastric Ulcer Scar

Gastric ulcer scar is visualized as a tiny barium pooling with relief convergence. Such a lesion can be stressed by image processing techniques. 17 cases (38%) were belonged in this group.

(d) Overlooked lesion

Although carefully checked by radiologists, a case was overlooked and missed.

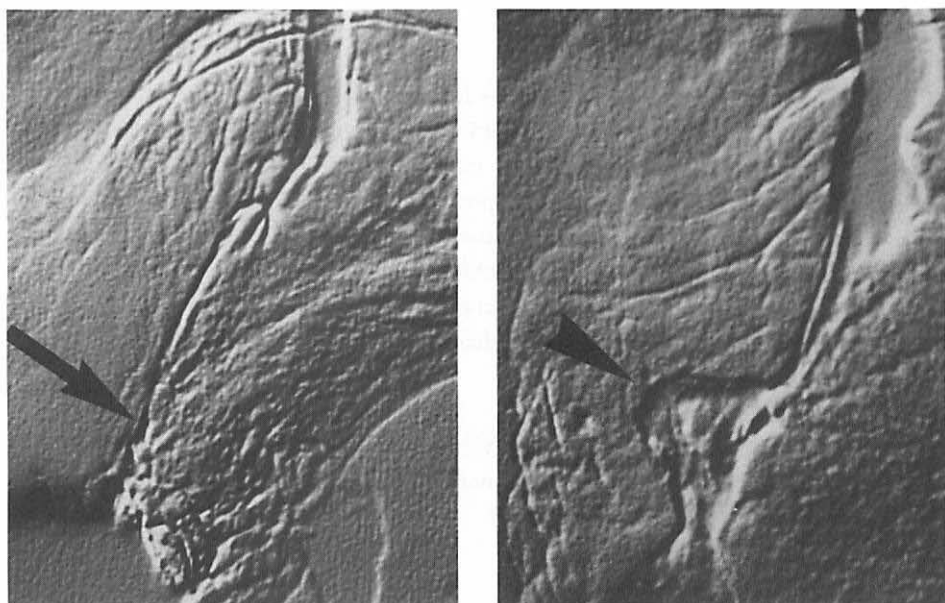


Fig. 2 Gastric cancer development visualized by Sobel operator. *left* : Irregular mucosal folds (arrow) are seen in 1987. *right* : Gastric cancer Borrmann I type (arrowhead) is found in 1989.

4. Discussion

Recent advances are found in development of 2048×2048 pixel image intensifier-TV digital radiography systems¹⁾. In the clinical evaluation Takahashi et al pointed out that digital images processed with unsharp masking techniques were comparable in quality to screen-film images before and upgrade of the system for the upper GI tract. Nakano et al indicated that high-pass spatial filtering enhances edge definition and increases visibility of the micromucosal pattern of the stomach in the computed radiography (CR)²⁾. For improvement of image quality, histogram equalization and grey-scale transformation facilitated better visualization of mucosal patterns in the underexposed or thinly barium coated cases³⁾. However, for enhancement of the lesion, Sobel operator or high-pass filtering is necessary.

Baba et al pointed out that most important figures of the depressed type in the early gastric cancer are (1) texture pattern on the depressed lesion composed with erosive and regenerated mucosa; (2) serrated margin of the depression, (3) converging mucosal folds, and (4) depth of the depressed lesion⁴⁾. Nakai et al pointed out that the size of a tumor was essential to estimating the extent of carcinomatous invasion into the gastric wall in gastric carcinoma with the protruded type⁵⁾. These characteristic figures are well visualized by image enhancement techniques; Sobel operator and high pass-filtering.

It can be said that the image processing techniques aid in analyzing tumor growth on the radiographs and in detecting phenomen in gastric cancer development from nonpathologic or pathologic mucosa. The results suggest that, with these image processings, malignant changes on the gastric mucosa may be detected in their early stage.

5. Summary

Computer image processing was used to enhance gastric lesions in order to improve the detection of stomach cancer. Digitalization was performed in 45 cases of early gastric cancer that had been confirmed surgically and pathologically. Utilized image processings were Sobel operator and high-pass filtering. Through investigation of processed images, we found cancer growing types. The results suggest that the image processings on stomach radiograph are beneficial to clarify early gastric cancer lesions by enhancing the pathologic lesions.

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New Automated Method for Registration of Bone Anatomy and Quantitative Evaluation of Changes in Alignment on Radiographs

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Abstract

We present a new algorithm for two-dimensional registration of musculoskeletal radiographic examinations. The technique determines a best match of bone anatomy by rotating and translating portions of digitized radiographs. To align the two images, the algorithm iteratively minimizes the variance of the ratio of one image to the other on a pixel per pixel basis. When the two images are not aligned, some pixels from the object of the one image are divided by pixels from another object or background of the other image creating a large variance. One geometric transformation (either rotation in the xy plane or translations along x and y axes) is adjusted with each iteration. A three-dimensional extension of the method is accomplished by adding adjustment to two rotations around the y and z axes and a translation along the z axis. Validation studies showed that the method is able to align images with an error less than 1 degree for rotation and 1 mm for translations. This technique allowed us to evaluate the changes in alignment of the spine in lateral flexion and extension films. This technique can be used to evaluate anterior and posterior listhesis, integrity of bone grafts status post spine fusion, and changes in alignment of fractures with standard radiographs.

Introduction

A significant number of radiographs are obtained to evaluate alignment of a fracture, alignment of the spine, joint replacements and internal fixation devices. Manual methods have been used to compare changes in alignment and degree of angulation and displacement. An automated method to calculate the degree of angulation, displacement and any interval change of alignment would be useful and could provide more reproducible results. We present a new algorithm for two-dimensional registration of musculoskeletal radiographic examinations. This method can be used to calculate degree of angulation, displacement and any interval

change. This method relies on relatively constant positioning with the assumption that the appearance of the bone anatomy stays constant except for alignment.

Materials and Methods

This technique determines a best match of bone anatomy by rotating and translating portions of digitized radiographs. To align the two images, the algorithm iteratively minimizes the variance of the weighted ratio of the two images. The weighted ratio image is computed by taking the ratio of the two images on a pixel per pixel basis and by assigning an appropriate weighting function. The operation of this function is to amplify the ratios between pixels that belong to different clusters and leave all other ratios untouched. A threshold which separates the signal from the background area is provided by the user or calculated in a preprocessing step. In this step the centers of $k=3$ clusters of the two images are computed with the k-means fuzzy clustering algorithm. These clusters correspond to background, low and high intensity signal. Pixels that belong to the background cluster are set to a steady value which is the center of the cluster, while signal pixels keep their original values.

Ratios between signal and background pixels are amplified by a monotonically increasing exponential weighting function of the signal intensity (figure 1), while ratios between signal areas are not affected. When the two images are not aligned, pixels from the object of the one image are divided by pixels from another object or background of the other image creating a large variance. One geometric transformation (either rotation in the xy plane or translations along x and y axes), the one with the largest variance derivative value, is adjusted with each iteration. The iteration loop extrapolates the variance function from n Chebyshev points for each transformation. The use of the weighting function, eliminated the local minima of the variance function and allowed us to limit these points to $n=4$ for 36 transformation units. The Newton Raphson method with the derivative of the variance is then used to calculate the point of minimum. This method was implemented on a SPARC 10 workstation (SUN Microsystems,) and written in C. The processing time was 1-2 minutes for 512x512 images with $n=4$.

Digitized x-rays of foot and knee phantoms were used to determine if this method could align bone structures taken in different degrees of rotation and translation. Ten degrees of out of plane rotation in addition to in plane rotation and translation was applied to one set of knee phantom images. The alignment algorithm can be applied to two different sections of the radiograph thereby allowing evaluation of the degree of angulation between two different bony structures. A modification of this method is to outline or segment the anatomical structures to be evaluated and then determine the degree of angulation or translation. Clinical examples of spinal fusion were used to compare this new automated method and traditional manual methods.

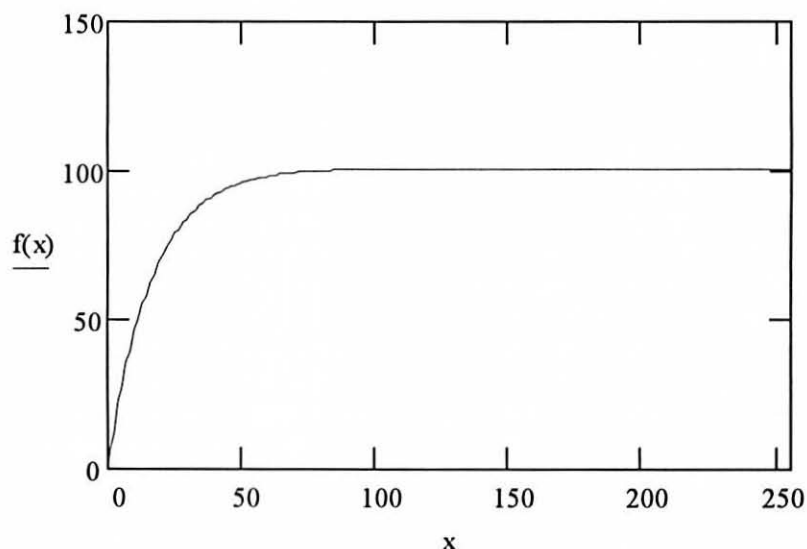


Figure 1 Example amplification weighting function (x pixel value, $f(x)$ amplification)

Results

Figure 2 demonstrates radiographs of a knee phantom taken in different degrees of rotation and translation. The registered image and a difference image are also shown. As can be seen there is good registration of the bone anatomy even with some out of plane rotation. The registration of the phantoms was considered good except when significant out of plane rotation was introduced or when one image contained significantly different anatomy such as 1/2 of the femur vs 1/4 of the femur. These problems can be minimized by standardized positioning and cropping of the digital image before processing. Studies of knee and foot phantoms showed that the method is able to align x-ray images with an error less than 1 degree for rotation and 1 mm for translations given the above constraints.

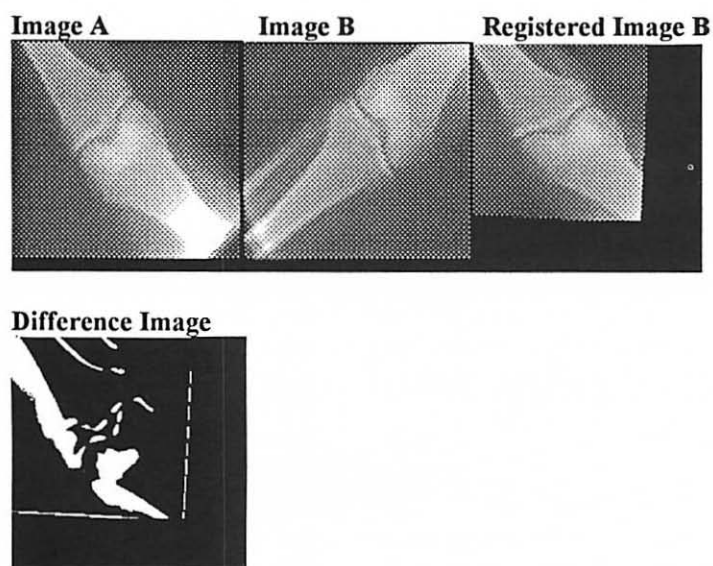


FIGURE 2 Original images, registered image and difference image of knee phantom

Figure 3 shows a method to evaluate changes in vertebral body alignment. The vertebral bodies to be studied are outlined manually and the filled outlines of each vertebral body are registered on flexion and extension films. Figure 3 shows registered images from a patient status post attempted fusion at the vertebral levels shown. By registering the upper fused vertebral body it is obvious that there is motion at the fused levels and the fusion is not complete. Comparison of manually aligned images and automated methods of alignment on clinical example radiographs showed good correlation.

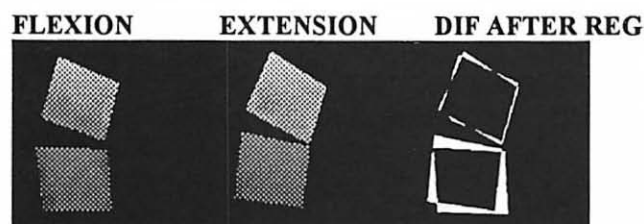


FIGURE 3 Outline of L4 and L5 vertebral bodies in flexion and extension in a patient status post attempted fusion. Registration of L4 vertebral body shows motion at the L4-L5 level demonstrating incomplete fusion.

Conclusion

We present a new automated method to register x-rays of bone structures. Preliminary studies on phantoms and several clinical images show that this technique can register x-ray images with an error of less than 1 degree for rotation and 1 mm for translation. This technique allowed us to evaluate the changes in alignment of the spine in lateral flexion and extension films. This technique can also be used to evaluate anterior and posterior listhesis, integrity of bone grafts status post spine fusion, and changes in alignment of fractures with standard radiographs. Further studies are necessary to determine the clinical utility of this technique.

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Texture Analysis of Trabecular Bone in Radiographs to Detect Osteoporosis

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1. Introduction

Osteoporosis is usually defined as a disease characterized by a diminished bone mass and an increased fracture risk. Fractures occurring due to osteoporosis are associated with an increased morbidity and mortality. In the past, several methods have been developed to measure bone mass. These methods assist in predicting fracture risk and monitoring patients undergoing treatment for osteoporosis. However, the reduction in bone mass is a consequence of a decrease in cortical thickness and in number and size of the trabeculae. As the strength of bone is determined by mass and architecture (1), a complete description of the osteoporotic state of bone should include, in addition to bone mass, a quantification of the architecture. The architecture of bone can be examined by using histomorphometric techniques. A less invasive way of looking at bone structure is offered by radiography, as changes in the trabecular and cortical structure are reflected in radiographs (2). Whereas cortical thickness can be measured directly by radiogrammetry, quantification of the trabecular structure is not as straightforward. The radiographic process reduces the three-dimensional trabecular structure to a two-dimensional image texture.

Texture is a rather elusive property of images. It can be described as the spatial distribution of different grey-tones in an image. In the image analysis literature a wide variety of methods for the quantification of texture can be found. However, the link between the quantifying features of texture and the texture visible in the image is often unclear. Texture features should be discriminated from first-order grey-level statistics, such as mean and variance of grey-levels, since these parameters do not describe the spatial distribution of grey-levels.

In this paper we explore the usefulness of a selection of texture features and first-order statistics for the discrimination of osteoporotic patients from their healthy contemporaries. We employed two methods of texture analysis: the spatial grey-level dependence matrix (SGLDM) method (3) and a method based on mathematical morphology. Repeatedly it has been shown that features generated by the SGLDM method perform better on classification tasks than other texture descriptors (4). A disadvantage of this statistical method is that there is no clear correspondence between the features and the textures perceived in the image. In contrast, features generated by the method using morphological operators are more easily correlated with the structures visible in the image.

2. Texture Analysis Methods

2.1 Spatial Grey-Level Dependence Matrix

The spatial grey-level dependence method, as described by Haralick et al. (3) , estimates the joint conditional probability distribution of the grey-values. The frequencies of co-occurrences of grey-values at a specified interpixel distance and in a certain direction are listed in a matrix. From this matrix, a number of texture describing features, such as homogeneity, contrast, correlation, and entropy, may be calculated. To ensure invariance under monotonic grey-tone transformations, the histogram of the image has to be equalized and requantified prior to the application of the SGLDM method.

2.2 Morphological Operators

Mathematical morphology provides techniques to describe shapes present in images. Morphological operations are defined by the convolution of a structuring element with the image. By varying size, shape, and direction (the morphology) of this structuring element, different morphological properties of the image can be highlighted. Serra (5) has defined the basic operations, erosion and dilation, for binary images. These operations can be generalized to grey-level images by using minimum and maximum filters. Also combinations of these basic operations can be performed.

As we are interested in oriented structures with a relatively high intensity on a dark background, an operation such as the white top-hat transformation is an obvious choice. When f represents the image and SE the structuring element, the white top-hat transformation is defined by

$$WTH_{SE}(f) = f - \gamma_{SE}(f)$$

where the opening γ of an image is defined as the erosion of I by SE , followed by the dilation of I by SE . This operation extracts the structures with a relatively high intensity, whereas background variations in intensity are eliminated. The size and the direction of the extracted structures is determined by the size and direction of the structuring element. When each transformed image is characterized by the sum of its grey-level values, varying the size and direction of the structuring elements yields a set of texture features (6). We applied a linear structuring element. Since we found that varying the size, within certain limits, does not yield additional information, we confined our analysis to one length of the structuring element. The orientation effect of the structuring element is shown in figure 1. After normalizing (to a standard mean and variance of grey-values) and smoothing the image, the following features were computed: the horizontal pixel sum (HPS) and vertical pixel sum (VPS).

3. Material and Methods

3.1 Material

High resolution radiographs were made of the right hand of 40 healthy persons and 40 osteoporotic patients. The diagnosis osteoporosis was based on the presence of vertebral fractures visible on the lateral spine radiographs. In the hand radiograph we selected two regions of interest which display visually a rather homogenous part of

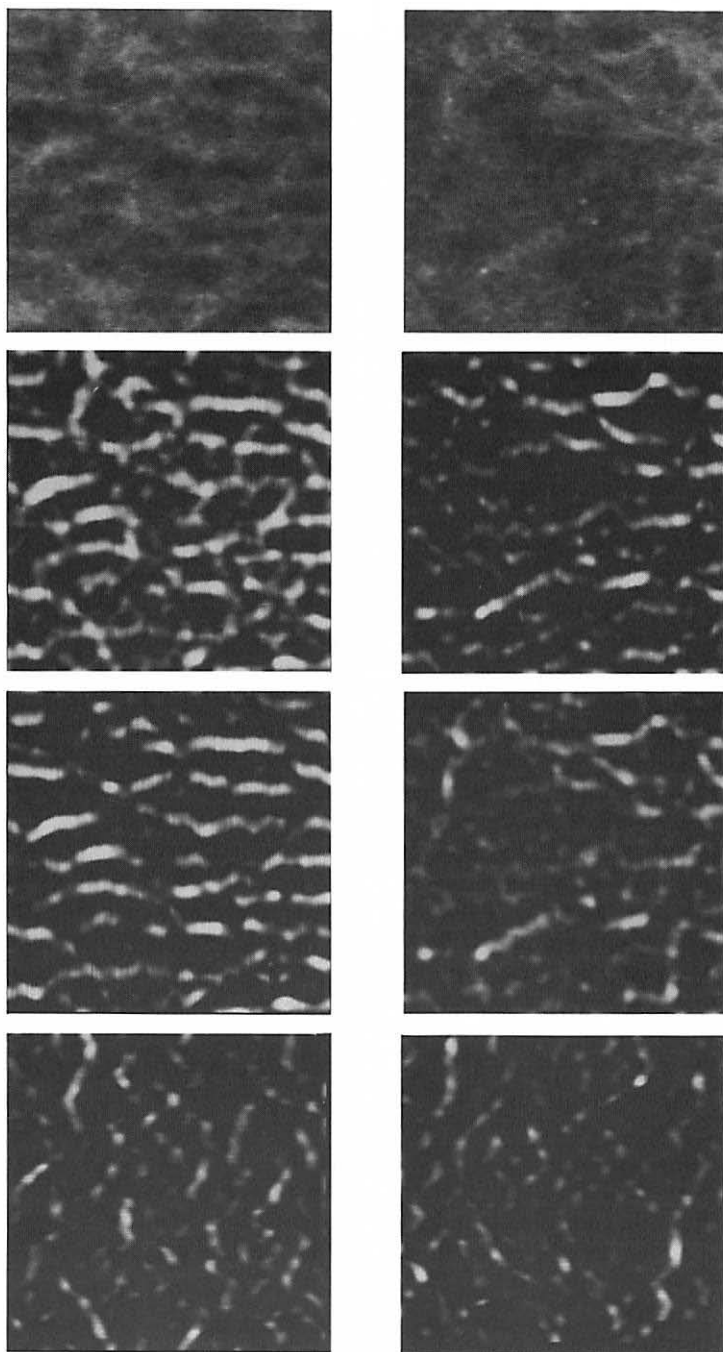


Figure 1 Trabecular structure (128 x 128 pixels) of normal (left) and osteoporotic bone (right) and resulting images of the WTH transformation. Size of structuring element from top to bottom 11 x 11, 1 x 11, 11 x 1.

the trabecular structure. One region is located at the proximal part of the metacarpal phalanx, the other at the proximal part of the middle phalanx, both of the right index finger. The area of both regions is approximately 3.5×3.5 mm. These regions were digitized by an 8 bits CCD camera using a pixel size of $25 \mu\text{m}$.

We used the method as described by Trouerbach et al (7) to obtain an objective measure for bone mass density. Here the bone mass density is calculated by calibrating the grey-values with the aid of a simultaneously radiographed aluminium wedge, and combining a lateral and PA radiograph of the right index finger. This bone mass density measure was determined at the proximal part of the middle phalanx.

Different preprocessing steps were applied for the two texture analysis methods. Before calculating the SGLDM features a histogram equalization to 8 grey-levels was performed. The morphological features were determined after normalizing the images to a standard mean and variance. A uniform filter was applied for smoothing.

3.2 Reproducibility

For our analysis we computed, for both regions, the following three groups of features:

1. First order : mean and variance of grey-levels
2. SGLDM : homogeneity, contrast, correlation and entropy
3. Morphology : VPS and HPS

The SGLDM features were calculated for different interpixel distances ($d=1$, $d=2$, $d=4$) in the direction perpendicular to the axis of the bone. In order to assess the sensitivity of the features for repeated digitization and region selection, 40 radiographs were digitized and analyzed twice. The average proportional difference of the feature values thus acquired, was determined. The region dependence of the features was determined by using the Spearman rank correlation test.

3.3 Feature selection and classification

For the classification experiment we computed for each feature an F-statistic. The F-statistic expresses the ratio of the between-groups variance and the within-groups variance. Classification was performed using the Fisher's linear discriminant based on the features with the highest F-value. Only features with an F-value exceeding a threshold value of 4.0 were incorporated in the discriminant function. Since it is known that in case of a limited sample size adding too many features to the classifier will, due to over-specification, not improve the classification performance, the dimensionality of the classifier was restricted to three. Discriminative power of the classifier can be expressed as the percentage correctly classified patients. For both regions, bone mass density and the above mentioned features were subjected to the F-test. Classification results of texture features alone and in combination with bone mass density were compared, in order to assess the added value of texture features in discriminating between osteoporotic patients and healthy persons.

4. Results

4.1 Reproducibility

The average difference between the feature values obtained from the two successively

digitized radiographs of the same person varies between 2.5 and 5 %.

The Spearman rank correlation test shows a significant correlation between texture features computed for the two regions of interest per radiograph ($P < 0.02$). However, the correlation coefficients are small (typically of the order of 0.3).

4.2 Classification results

For both regions and for both texture-analysis methods, the (combination of) features with the highest value for the F-statistic were determined. The correct classification rate (CCR) of the selected texture features, alone and in conjunction with bone mass density, are listed in table I.

Table I The classification rates of the texture features

Phalanx	Method	Feature	CCR	CCR with bone mass density
Middle	SGLDM	Bone mass	76.25	
		Homogeneity ₄	68.75	71.25
		Morphology	57.50	72.50
		SGLDM and Morphology	68.75	71.25
Proximal	SGLDM			
		Morphology	63.75	78.75
		HPS and Variance	73.75	80.00
		SGLDM and Morphology	63.75	78.75

For both regions, bone mass density alone is a better discriminator than any of the texture features. Except for the SGLDM features in the proximal phalanx, all texture features yielded comparable results in terms of discriminative power. When the morphological feature HPS is combined with the grey-level variance, a first order statistic, its performance, in the proximal phalanx, is improved. The discriminative power of the texture features is slightly improved by adding bone mass density to the classifier. However, the resulting classification rate is still lower than that of bone mass density alone.

5. Discussion

Osteoporosis is characterized by a change in bone architecture as well as by a reduced bone mass, resulting in an increased fracture risk. At present, bone mass is used as

the main predictor for fracture risk. Since the architectural changes in the trabecular bone are reflected in radiographs, features expressing texture can be used for extracting structural information from radiographs. In this paper we have investigated the usefulness of two sets of texture features in discriminating osteoporotic patients from healthy persons. It was then investigated whether the texture features have additional discriminative power when combined with a measure of bone mass density. To determine the reproducibility of the texture features, radiographs were digitized and analyzed twice. The relatively small average proportional difference between the features thus computed implies that the features are relatively stable under redigitizing and repositioning of the region of interest. The reproducibility of the features is therefore satisfactory. Although the texture features determined in the two regions are significantly correlated, classification results for the two regions are not directly comparable. This discrepancy may be explained by the rather small correlation coefficient. The usefulness of the different features has to be evaluated in relation to the selected region. Proper region selection is of major importance to the successful application of texture features. Since morphological features have a clear correspondence with visually perceived structures, in contrast to the statistical method, these features are suitable for guiding region selection.

The classification results show that bone mass density is a rather good discriminator between osteoporotic and normal bone. Whereas the texture features generated by the SGLDM method and the morphological features display an obvious discriminative power, combining these parameters with bone mass density results in classification rates which are below the performance of bone mass density alone. Hierarchical classification may improve the classification results.

For the proximal phalanx, a morphological feature (HPS) in conjunction with the grey-level variance yields the best classification result. It should be taken into account that the discriminative power of the grey-level variance can originate from different x-ray exposure conditions for the healthy persons and osteoporotic patients. By calibrating the grey-values and so expressing the variance in terms of bone mass per area, a more objective first-order statistic can be obtained. Texture features should be independent of first-order grey-level statistics. By adding these features separately to the classification process, their contribution to the classification can be made explicit. In future research the discriminative power of other texture features and calibrated first-order statistics will be investigated.

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SESSION 3

3-D Imaging

Chair: David Beard

Interactive 3D Processing on a Standard MRI System

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1. INTRODUCTION

Progress in magnetic resonance imaging (MRI) coincides with the development of fast, inexpensive workstations and sophisticated software for image display and manipulation. Incorporating these changes in imaging technology, MRI system designers try to find the most effective combination of capability and efficiency.

Most MRI systems consist of a host computer with an array processor for the more compute-intensive applications. As the discipline matures and users become familiar with image processing concepts, the demand for more functionality encourages manufacturers to expand the system architecture. One direction of this expansion is to increase the power of the array processor.

Array processors have become much faster in the last few years as a result of ever-improving chip designs. Also, the development of parallel processing has facilitated the use of multiple CPUs on a single board [1]. These array processors present the software engineer with some opportunities to make significant enhancements to an MRI system.

2. METHODS

Our MRI system has a Silicon Graphics 4D/35 workstation with a Mercury Computer MedCam array processor. The array processor has four Intel i860 CPUs, each with 16MB of DRAM, 8KB of cache, and a private 160MB/sec bus to move data between what Mercury calls the "compute environments", *i. e.*, the four CPU-memory subunits. Data can move from one compute environment (CE) simultaneously to each of the other three, for a total bandwidth of 480MB/sec.

A typical application will generate five processes, one for the host and one each for the four CEs. One of the CEs acts as the master process and the other three are slave processes. Inter-process communication is done with sockets. The host process runs the user interface, sends data and parameters to the master CE process, and displays the resulting data. The master CE process distributes some of the data and parameters to the other three CEs, so that all four can work in parallel.

We wrote some of our code to be able to use any number of CEs so we could compare processing speeds. Many imaging applications derive no benefit from the extra CEs, since they involve simple algorithms and do not require more than the 16MB of memory available to a single CE. We will confine our discussion to applications that take full advantage of the MedCam architecture.

3. RESULTS AND DISCUSSION

Adaptive image enhancement

The adaptive image enhancement application is a multi-step, multi-parameter filter algorithm which is an ideal candidate for parallel processing. Each of the steps entails four one-dimensional convolution filters in different directions (horizontal, vertical, and the two diagonals), performed independently, and the four resulting images are combined as a pixel-by-pixel weighted sum.

Because each convolution is applied in four directions, it is natural to assign CE to a direction. The result of the filter remains in the local memory of the CE until the four convolutions are all complete and ready to be combined by the master CE. The filters can be modified by user-selected parameters. Since the filtered images are combined sequentially, whenever the user changes one parameter some of the calculations may not have to be performed again. Response times range from 800 msec for the full operation (including disk read) to under half a second for a single parameter change and redisplay.

On our older, slower systems individual parameter selection was too time-consuming (up to 8 seconds per image) to be practical in a clinical setting where patient throughput is important. The manufacturer provided a limited menu of parameter sets as options which the technologist or radiologist would have to preselect for an entire study based on *a priori* knowledge of the characteristics of the the anatomy, and the pathology being examined.

In an interactive process, the manipulation of the filter parameters can be a learning aid as well as a practical way to maximize image quality. The immediate feedback helps the operator to assess the effect of increased smoothing or edge sharpening, and this assists in selecting the ideal parameters for a given image.

Maximum intensity projection (MIP)

Much recent work in MRI involves imaging of blood vessels. It is hoped that at least some of the risky and invasive x-ray angiography (XRA) examinations currently used for diagnosis of vascular pathology can be replaced by magnetic resonance angiography (MRA).

Most MRA sequences produce images in which the blood vessels are the brightest (highest intensity) features. A relatively simple and effective (and therefore popular) way to present these images is a three-dimensional ray projection technique called maximum intensity projection (MIP). For any desired view of an image volume, a series of parallel rays is projected through the volume, and the highest intensity pixel encountered becomes a pixel in the projected view. In this simple version, no depth information is retained, so the operator typically generates several views at different angles and then displays them sequentially to get a sense of rotation and the relative positions of vessels.

Due to the non-cubic voxels of MRI images and to the need for many view angles, MIP requires a great deal of interpolation. 256x256x64 voxel data sets are not uncommon, although the operator needs to select a subset ROI not only to reduce the number of calculations but also to eliminate obscuring anatomy (usually fat), so that 128x128x44 is more representative of a useful MRA volume.

Unlike the adaptive filter algorithm, which divides conveniently among four CEs, MIP can easily use one to four CEs, so we configured it to be selectable in order to measure the throughput improvement of each additional CE. For the following calculations, we used a 128x128x44 volume, voxels measuring .81x.81x2.0mm, and we zoomed the images a factor of 2. Projections at 90 degrees and 45 degrees are much faster than other angles due to significantly less interpolation. Times are in the table are approximate and are in milliseconds.

<u>CEs</u>	<u>90.0</u>	<u>67.5</u>	<u>45.0</u>	<u>22.5</u>
1	1740	3270	1810	3460
2	1350	2090	1370	2180
3	1260	1780	1250	1840
4	1180	1530	1150	1580

The most significant speedup is seen with angles requiring the most interpolation, such as 22.5 degrees. With a single CE it took almost 3.5 seconds to produce a view, while with 4 CEs it took less than half that time.

Note that these rotations were about the horizontal (X) axis of the original volume. Rotations about the vertical (Y) axis are slightly faster because the pixels are stored contiguously in the X direction, so the page boundaries of DRAM are not crossed as frequently. This effect is minimized, but not eliminated, by the use of the 8KB cache.

Multi-planar reconstruction (MPR)

MPR is similar to MIP in that it creates rotated views of volumetric data. These views, however, are cut planes rather than ray projections. As of this writing, we had not optimized the MPR code, so the absolute time to produce a view may not be the best this architecture is capable of, but the relative times for multiple CEs once again show a significant improvement (ROI = 128x128x44).

<u>CEs</u>	<u>67.5</u>
1	5010
2	2980
3	2420
4	2010

4. CONCLUSION

In our experience developing imaging software for MRI systems we have frequently encountered situations where added capabilities result in slower response time. For example, we added an adaptive filter to the image display software which doubled or tripled the time to paint an image on the screen. In general, the users of the system became vocal when the time to paint approached four seconds. (We call this the "annoyance threshold".) Some operators even chose not to use the filter because of the slower response time.

Assigning time-consuming functions to background processes frees the system for other uses, but it sacrifices the benefit of immediate feedback in cases where the operator must select parameters which may determine image quality.

For the three applications described here, the addition of three compute environments running in parallel with the master CE resulted in good response times, while the same applications were near the "annoyance threshold" when run with a single CE.

5. ACKNOWLEDGMENTS

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Integrated Image-Processing with Spiral-CT, 3D-CAD and Direct Implant Casting with Stereolithographic 3D-Solid Models

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Summary:

Preoperative planning and computer assisted surgery techniques are going to be used in several medical specialities. Although several progresses have been made according to precision and accuracy of the scanning procedures and 3D-image processing CT- and MRI-examinations. But up to now there is no acknowledged method available for transferring -for instance- resection plannings based on the the 3D-images back to the patient and the surgical procedure.

The potential of Spiral-CT, 3D-CAD and Sterolithographic models for direct implant- or supporting structures construction will be discussed as an alternative to overcome this disadvantage.

Introduction:

Since fast volume scanning methods became available in clinical routine several progresses were made to increase the quality of 3D-reconstructions based on CT- or MRI-images. But there are still three main drawbacks:

1. These procedures have been used as a kind of presentation tool, providing impressive images with usually limited clinical relevance. In most cases it was necessary to extend the CT-or MRI-examination by the use of small slice thicknesses and intervals to get a sufficient spatial resolution for 3D-reconstructions.

2. Common image-workstations are limited to 3D-reconstructions with volume rendering or raytracing methods. Most of the systems on the market do not provide any tools for real interactive manipulations of the 3D-images like they are needed for surgical resection planning or accurate implant-construction.

3. Beside some stereotactic and neurosurgical tumor-resection - techniques with intraoperative use of preoperative acquired scanning data and plannings, there are no accepted methods for the transscription of preoperative calculated surgical procedures into the operation-room.

In order to overcome these drawbacks our group is working as a member of the medical section within the „European Concerted Action on Rapid Prototyping“ (EARP) on an integrated solution for high-resolution scanning, 3D-manipulation and interactive procedure planning. As a part of technology transfer of industrial state of the art production methods, the use of rapid prototyping is the main subject of our study.

Material and methods:

1. Scanning procedure:

According to the complex bony structures of the craniofacial region and the limited 3D-information within conventional multiaxial radiographs, which are commonly used by the surgeons for detailed procedure plannings, most of the cases were done on patients with severe fractures or dysplasia of this region. All patients were scanned with Spiral-CT's, using 1 or 2mm slice thickness and tablefeed. The increment between two images was always equal to the original slice-thickness. Two or three continous 40 sec Spiral-CT's were needed to sacn the whole craniofacial region. All raw-data were stored to provide post-examination recalculations. All patients were examined with dose-reduced Spiral-CT's. The therefore slightly increased noise-level of the images was diminished with medium edge-enhancement reconstruction algorithms.

2. Image processing:

All images were 3D-reformatted using the conventional 3D-software of the CT-scanner (Siemens Somatom Plus S) to control the scanning procedure and to provide an 3D-overview. All areas of certain interest were marked within the 3D-image and reconstructed by primary zooming of the stored raw-data. All images were transfered by network to the imaging console (Silicon Graphics). All bone contours were extracted with a specialized software and converted from voxel

to a trigonometric data format, which is used in a 3D-CAD system providing surface modelling (CISIGRAPH STRIM 100). Procedures like cutting and moving, as well as precise 3D-construction were available on this standard industrial system.

3. Implant construction and supporting structures:

The shapes of the calculated implants and supporting structures were converted into a stereolithographic file and has been exposed on an standard stereolithographic machine (3D-Systems). The result was a solid 3D-copy of the interactive calculated and constructed structure, which can be used for direct casting of the final ceramic or metall material.

Results:

Although there are still detectable differences between high-resolution conventional CT and Spiral CT all 3D-reconstructions of Spiral-CT images were superior compared to the conventional 3D-images. This is caused by the reduction of patient-movements during the examination and a scanning method depending slight smoothing effect. There was no perceptible difference between images calculated with either 360° or 180° algorithm as long as 1 or 2 mm slice-thickness was used. But the main advantage of the Spiral-CT was reduction of the examination-time: Even children could be examined without general relaxation.

There is still interaction necessary for the image segmentation, although we could use an advanced segmentation program for the extraction of the bone structures. Once the images were converted to the CAD-system all 3D-tools of the system could be used for the construction of the needed implants and planned resections. Therefore it was possible to construct individual implants in order to reduce interoperative fittings and therefore operation-time.

By the use of rapid prototyping techniques like the stereolithographic modeling and direct implant casting, it is possible to reconvert computer aided and generated structures into solid 3D structures with a certain accuracy. The overall resolution and precision of the whole technical procedure is always higher than of the primary CT-scanning. The 3D-stereolithographic printout can be used as a positive shape for direct casting of materials like ceramic [7] or different metals.

Unfortunately 3D-CAD systems are much more complex than conventional medical image workstations and require detail experience of the modeling principle which is very often timeconsuming.

Discussion:

The advantages of 3D-visualisations have been proven in several studies [1,2,3,4]. But in most cases it is still used only as a kind of presentation tool. The 3D-image quality still depends on several scan- and reconstruction parameters [5], but in our opinion high-resolution spiral CT is a basic assumption for a „constructive“ approach like implant development. Although stereolithographic modeling adds real new therapeutic aspects to 3D-visualisations, it is in most cases still used as an -unfortunately very expensive- presentation tool.

In our opinion the next step towards preoperative interactive construction became possible with advanced imaging, 3D-CAD and rapid prototyping. Several applications are going to become available and have to be proved in further studies.

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Advanced Tools for 3-D Processing of Tomographic Slices

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Introduction

The techniques and applications for 3-D visualization of CT and MR have become more advanced in recent years. Most recently, the 3-D visualization of vasculature acquired with CT, also known as CT Angiography (CTA) (1), has become possible with the application of the Maximum Intensity Projection (MIP) technique(2). As imaging methods are becoming more sophisticated, there is a greater need to process data prior to 3-D rendering to ensure that organs of interest are not obscured. For example, the MIP technique works properly only if the organ to be imaged is of the highest intensity along the projection path. In order to depict vessels in CT data with MIP, bone must be removed so that it does not obscure the less dense vascular lumen. Up to 150 axial images can be acquired in a single examination, which makes the interactive editing of individual slices an extremely tedious and time consuming process. The effort involved in preprocessing the data could defeat the utility of the imaging technique.

A system has been developed that speeds up the preprocessing step by grouping the entire stack of slices into several subsets or slabs. Each slab is processed by manipulating an image that is a maximum intensity projection of the entire slab, and propagating the manipulations to each slice in the slab. Thus, the processing time is reduced by a factor that is the average number of slices in a slab. By manipulating a MIP of a slab, one can very easily identify the bones in a CT volume since they are of the highest intensity. This method applied to the CT imaging of vasculature has provided a significant savings in preprocessing time over the conventional, one slice at a time, approach. The slab method could be coupled with any existing segmentation method applicable to a single slice, such as region growing or edge detection, to greatly speed up the processing of a series of images.

Need for Segmentation

The MIP algorithm consists of ray casting through a volume and projecting the maximum intensity values encountered by the rays onto a final image (3). A limitation of such a technique is that the highest intensity structures in the volume obscure all others. The MIP technique is effective in depicting vessels imaged with CTA only if the contrast-enhanced vessel lumen is of greater intensity than all other structures. The presence of bone in the volume violates this condition, as the vessels are obscured by the superimposed bone. The bone must be edited out from the volume in order to effectively visualize the vessels. Although some automated techniques exist for bone segmentation, the most reliable method is manual editing (4-6).

Slab Editing

An editing system was developed that processes the entire image stack, instead of individual slices. The technique takes advantage of the fact that, in most cases, the location of bone does not significantly differ in adjacent slices. By looking at a cranial MIP view of several adjacent slices, one is easily able to determine the greatest extent of the superimposed bone structures. This is due to the fact that bone almost always represents the highest intensity values in a CT slice. By choosing an appropriate number of slices in such a subset, one can insure that the composite bone projection does not obscure the composite lumen projection. Under this condition, it is possible to encircle the bone structures without encircling any of the vessels. Such curves can be propagated to individual slices to remove the bones.

The time savings comes from the fact that editing operations are applied to groups of slices instead of individual images. Such groups are called slabs. Slabs are selected graphically by displaying a lateral MIP view of the entire image stack and selecting the slab borders on the image (Figure 1).

Upon the definition of the slabs, the operator will define a contour for each slab using the cranial MIP view of the slab (Figure 2). This contour will be propagated to each slice in the slab and will be used to eliminate all data outside the contour. Thus, the bone will be eliminated while preserving the vessel information. The user defines the contour by specifying a number of vertices, which are the end points of the contour segments (Figure 2). The contour can be modified by moving these vertices. In most cases, the shape of the contour need change only slightly between adjacent slabs. Thus, the operator need only move a few vertices to define the correct contour, as the contour from the slab is preserved. Once all the contours are defined, the images are modified.

Results

This editing technique was applied to over 25 CTA cases. All the processing was done with the VRT program of the Siemens SOMATOM Plus CT scanner. Figure 3a shows a CTA study rendered with MIP before editing. Figure 3b is the MIP depiction of the same case with the bones removed using the slab editor. The editing was accomplished in three minutes. The case contains 147 slices that were grouped into 10 slabs. Figure 4 shows another CTA case edited with the slab editor. This case was edited in 7 minutes. It has 80 slices, which were grouped into 13 slabs. The results of the two cases were representative of the results obtained for the rest of the cases.

Discussion

The MIP rendering in Figure 3b clearly demonstrates the extent of the mural calcification, while providing a vivid picture of the rest of the vasculature. The infrarenal aortic stenosis in Figure 4 is also very well depicted with MIP. The results demonstrate that anterior depictions of the vessels are not possible without removal of bone. Manual editing of such CTA cases may take anywhere from 30 minute to an hour. The use of slab-based editing cuts down the preprocessing time to about 5 minutes. This time savings greatly reduces the level of difficulty necessary to obtain good MIP CTA images, and it is an important factor for the eventual acceptance of CTA as the clinical routine.

Although the current implementation allows only manual editing of slabs, automated techniques can also be applied. Connectivity or automatic bone detection algorithms applied to slabs would also be sped up by a factor that is an average number of slices in a slab.

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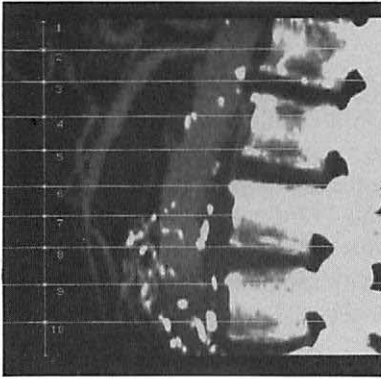


Figure 1. Selection of slabs from a lateral MIP reference.

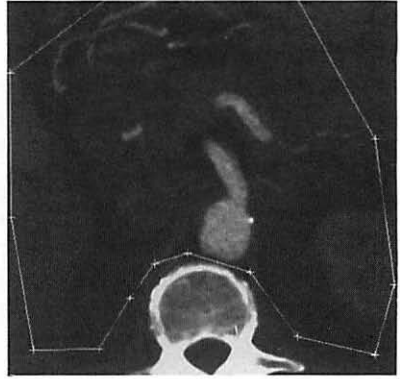
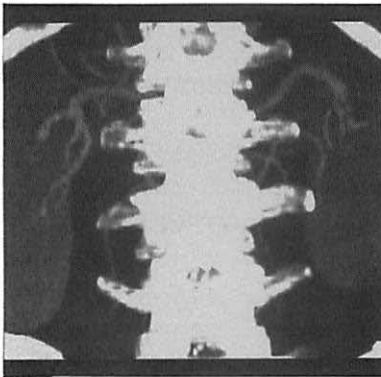


Figure 2. Definition of a bounding contour on top of a MIP view of a slab.

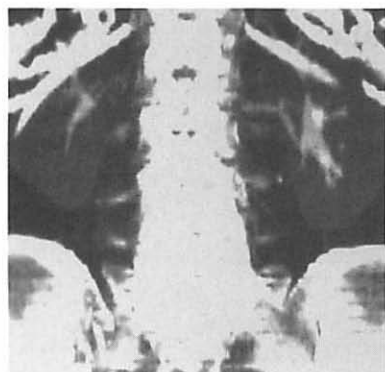


(a)

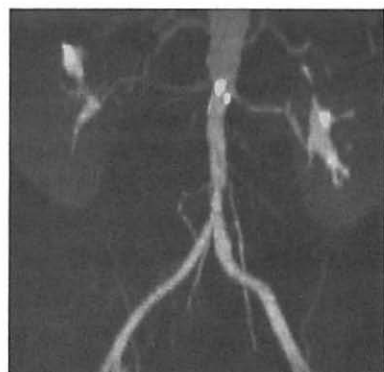


(b)

Figure 3. MIP depiction of a CTA data set without (a) and with (b) editing. The slab editor was used to remove the bones. A mild stenosis of a lower pole, left renal artery is demonstrated (arrow).



(a)



(b)

Figure 4. MIP rendering without (a) and with (b) bone removal. Slab editing was used to remove bones. An infrarenal aortic stenosis and mild renal artery stenoses are observed.

Interactive 3D Medical Visualization: A Parallel Approach to Surface Rendering 3D Medical Data

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I. INTRODUCTION

Using Pixel-Planes 5, a parallel multicomputer for computer graphics [Fuchs 90], we have constructed a system for visualizing volumetric medical data based on polygonal approaches to surface rendering. The goal is a medical visualization system that has intuitive navigation and exploration capabilities to present 3D clinical data using three dimensional images. To provide a natural navigation of patient data, segmentation parameters should provide user feedback at minimum rates of one update per second, and viewing direction and lighting control should respond in tenths of seconds. Our approach differs from other methods under investigation at UNC [Yoo 92] as we take advantage of the hardware graphics accelerators for polygon rendering rather than attempt direct volume rendering.

II. BACKGROUND

Fuchs and his colleagues developed an approach for generating surface models from 3D slice-based medical data. Their method uses extracted contours of anatomical elements on individual slices. The contours are subsequently stacked, and a polygonal model is generated by interpolating surfaces between the segmented curves [Fuchs 77]. More recently, Lorensen and Cline circumvented the intermediate contour generation stage using an algorithm called "*Marching Cubes*" that generates polygonal representations of the anatomy directly from the segmented volume data [Lorensen 87][Cline 88].

There is a continuing debate over the relative merits of surface extraction as a presentation method versus direct volume rendering. In particular, *marching cubes* suffers from an algorithmic flaw which leads to mathematical inconsistencies, violating the "Jordan Property" [Kong 92]. That is, the algorithm does not guarantee that the generated polygonal representations are closed orientable surfaces (that they partition space into sets of 'inside' and 'outside'). Other investigations comparing surface and volume rendering have based their findings upon the expected memory requirements and computational load imposed by the various methods [Udupa 91].

We contend that developments in parallel computer architecture enabling fast computation and rendering have removed many of the obstacles to effective volume visualization through surface rendering. In particular, interactive generation of the

polygonal representation of anatomical surfaces coupled with real time control of the display overcome many of the visualization problems in surface rendering techniques. Visualization flaws arising from the non-oriented surfaces generated by *marching cubes* may be easily overcome by interactively modifying the segmentation parameters and checking the persistence of anomalous features through different segmentations.

Moreover, approaches to volume visualization based upon polygons as primitives take better advantage of today's graphics accelerators. Systems capable of processing in excess of 200 thousand shaded triangles per second (Sun Microsystems Leo) to a half million shaded triangles per second (SGI Extreme Graphics) are now commercially available.

III. DISPLAY ARCHITECTURE

Our development platform, Pixel-Planes 5, is a heterogeneous graphics architecture using both MIMD (multiple instruction multiple data path) and SIMD (single instruction multiple data path) parallelism. This machine has multiple i860-based Graphics Processors (GPs), and multiple SIMD pixel-processor arrays called Renderers. Each Renderer is a 128x128 array of pixel processors capable of executing a general purpose instruction set. GPs send Renderers opcode streams which are executed in SIMD fashion. The GPs, Renderers, several Frame Buffers, and a workstation host communicate over an eight-channel ring-network whose bandwidth is 80 MB per channel (aggregate bandwidth of 5 gigabits per second).

IV. IMPLEMENTATION

We parallelized the *marching cubes* algorithm, optimizing the implementation for Pixel-Planes 5. Questions examined in this research include how to subdivide the data among multiprocessors and how to accelerate the surface extraction given the subdivision. Data must be distributed so that the computational load is balanced among the processors. Figure 1 shows a schematic of the data and command flow for *marching cubes* on Pixel-Planes 5. The MIMD section is responsible for the construction of the surface models, performing geometric viewing and lighting transformations, and finally invoking the SIMD Renderer units, sending opcode streams to render the polygon primitives of the model. Figure 2 shows a description of the system implemented on the individual graphics processors. The sequence of processing steps include: dataset distribution, voxel gradient estimation, interactive user segmentation and generation of the surface model, geometric viewing transformation, and distributed rendering.

Dataset-distribution: Typically, X-ray CT and MRI data have significantly higher resolution in two of the major axis dimensions (x and y), and are fairly sparse in the third (z) dimension. After some consideration, we elected to preserve the orientation of this innate coordinate system of the medical data, and distribute the data as sets of X-Y slices. Overlapping slice sets, four contiguous slices each, are distributed in a round-robin fashion among the available graphics processors.

Gradient estimation: The data in its initial distribution is replicated four times throughout the processors. A method of central differences is used to estimate the

gradient vectors at each voxel location. After this calculation is complete, two of the four data slices may be discarded. This step results in estimated normals for rendering smooth surfaces and reduces the data replication by fifty percent.

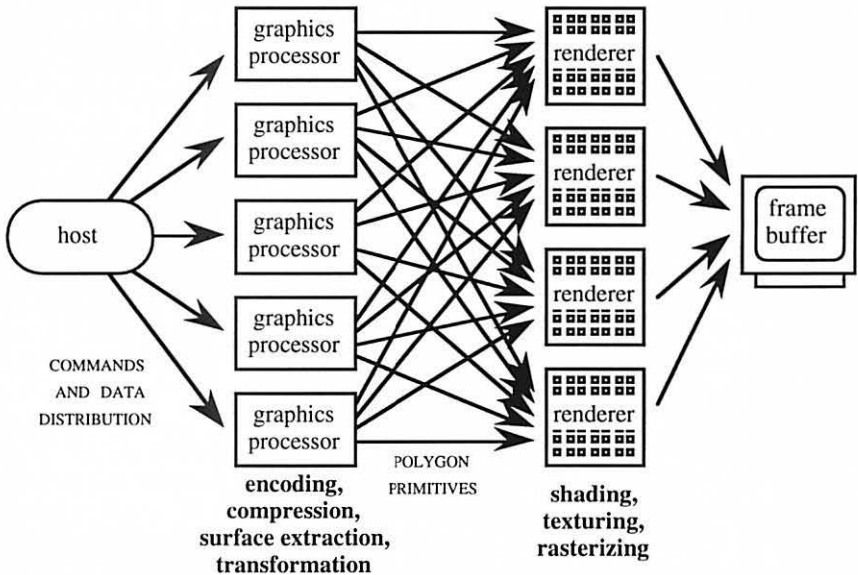


Figure 1. - Schematic of the Pixel-Planes 5 *marching cubes* algorithm

Interactive segmentation (isosurface selection): User controlled inputs supplied via the host interface are broadcast among the graphics processors. Upon receipt of new threshold information the processors use the *marching cubes* edge intersection calculations and polygon lookup tables. A table based approach, though prone to interpolation error proves to be one of the fastest mechanisms for computing polygonal surfaces.

Interactive viewing control and distributed rendering: Parallel rendering is accomplished using the existing graphics software infrastructure. Polygon primitives are transformed to screen space coordinates, and the resulting polygon primitives are distributed among the Renderers for rasterization to one or more frame buffers. Pixel-Planes 5 is capable of sustained frame rates of 20 frames per second and polygon rates exceeding 2 million smooth (Phong) shaded triangles per second.

V. OPTIMIZATIONS

The slice based data distribution suggests raster based encoding for data compression. Run length encoding provides both a mechanism for memory optimization and a means of traversing intervals between isosurface boundaries. Run-length encoding accelerates the intersection calculations for edges along the compressed row. The isosurfaces will not intersect edges between voxels of the same value. So the edges that are between voxels of similar value may be skipped. No such acceleration is attempted for edges across rows or between slices.

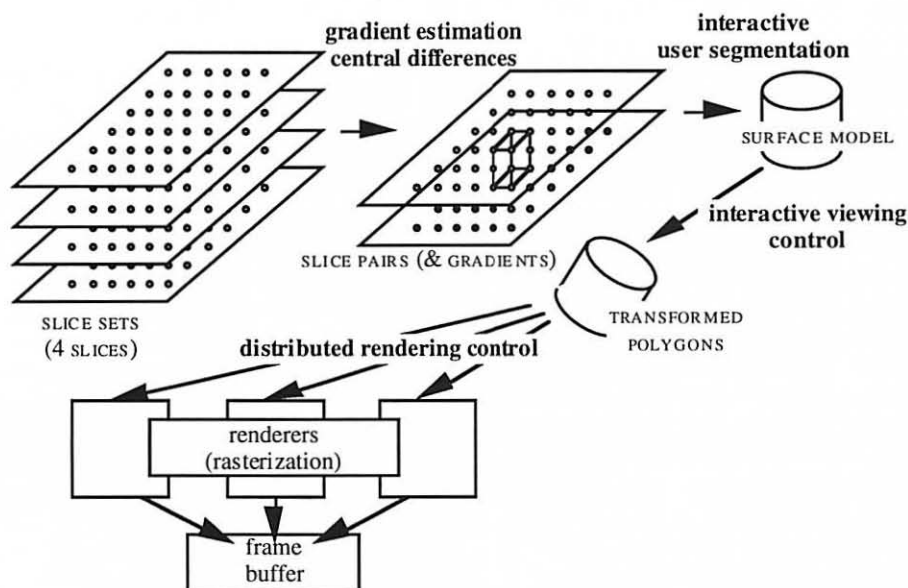


Figure 2. - The parallel *marching cubes* pipeline

VI. RESULTS

Using the data distribution and control flow described in the previous sections, we constructed the system and measured its performance on several different data sets. The Pixel-Planes 5 configuration that we used included 36 graphics processors and 16 Renderers which represents approximately 60% of the maximum configuration.

Figures 3 through 5 show a CT pelvic study (128x128x56 voxels) displaying between 40,000 and 110,000 triangles at frame rates of between 8 and 20 frames per second (depending on the complexity of the representation). The system can perform 2 to 3 isosurface calculations per second of this data. Figure 6 is a rendering of volume ultrasound data (128x64x96 voxels) of the face of a human fetus in utero. The surface model was generated in 357 milliseconds. The surface is rendered at 871 thousand polygons per second (12 frames per second). Figure 7 is an MR study of a human female (resampled to 96x96x109 voxels). The surface model was generated in under 6-tenths of a second and contains 269720 triangles. Because of the complexity, the view update rate is limited to 3 frames per second.

VII. RELATED WORK

Alternate approaches to parallelizing volume visualization through surface rendering have been developed in conjunction with different architectures. Notably, significant effort has been extended in the development of SIMD algorithms for fine-grain massively parallel surface extraction [Hansen 92][Song 93]. Alternate image analysis encoding may be employed if the volume is not subdivided. Wilhelms and van Gelder explored octree based sorting and searching algorithms to accelerate the generation of surface models [Wilhelms 90].

Finally, simplifying the surface representation is a straightforward approach to increasing the speed of rendering complex surfaces. Graphics and visualization literature contain several algorithms for simplifying polygonal models [Schroeder 92][Turk 92][Hinker 93]. Each of these methods are hindered by the distributed nature of volume data in our implementation and subsequently were not incorporated.

VIII. INTERACTIVE HEAD-MOUNTED DISPLAYS

Fast polygonal rendering enables the technology of virtual reality along with its many applications in medicine [Bajura 92]. The emphasis of this work has been to provide fast, natural, interactive navigation of 3D medical data. We have implemented a prototype VR interactive medical display (Figure 8). The future may lie in more personal presentation of volume data through VR. The applications and opportunities to the field of computer aided medicine are manifold, and are yet to be explored.

ACKNOWLEDGMENTS

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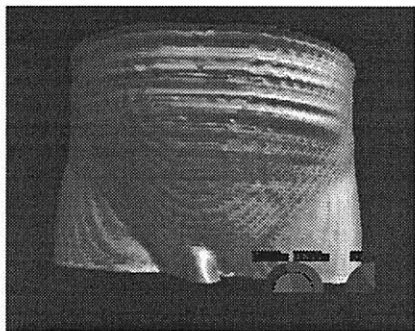


Figure 3. - X-ray CT Pelvic Study (128x128x56 voxels). Skin surface (41708 triangles) generated in 409 msec. View update rate 20 frames/sec (fps)

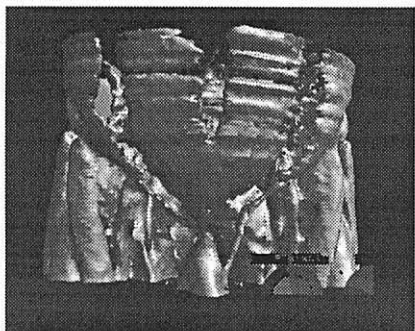


Figure 4. same study as Figure 3. Muscle surface (110450 triangles) generated in 676 msec. View update rate 8 fps

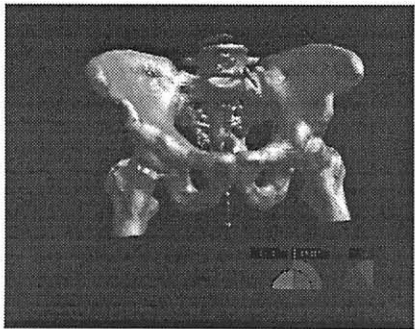


Figure 5. - same study as Figure 3. Bone surface (49552 triangles) generated in 409 msec. View update rate 19 fps

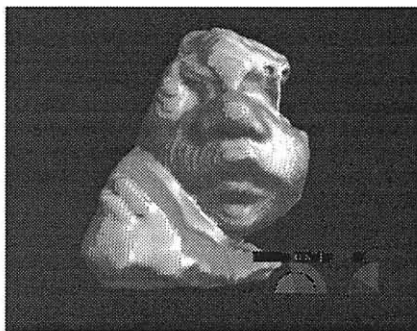


Figure 6. - Volume ultrasound of human fetus in utero (128x64x96 voxels). Face (70874 triangles) generated in 357 msec. View update rate 12 fps

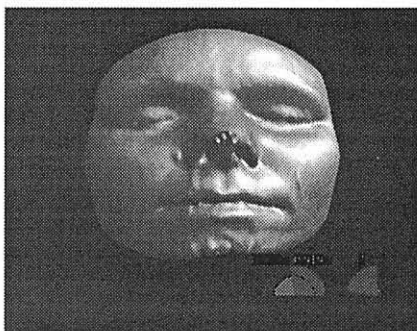


Figure 7. - MR head study (96x96x109 voxels). Skin surface (269720 triangles) generated in 591 msec. Update rate 3 fps

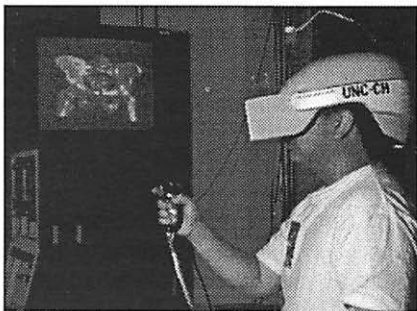


Figure 8. - David Chen pictured using a head mounted display. Stereo surface renderings are presented in a virtual environment for medical visualization.

Motion Estimation in Dynamic MR Studies

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I. INTRODUCTION

Dynamic MR image sequences are acquired to study either the movement of an organ, e.g. the heart, or the dynamic behavior of signal intensity in different tissues following contrast agent enhancement with the aim of extracting functional information. Studies are disturbed by involuntary patient movements, which may cause incorrect data processing and errors in the evaluation of the quantitative and dynamic parameters. For the automated analysis of sequences, it is essential to detect and correct inter-frame motion by registering the images [2].

The registration of an image pair necessitates implicit or explicit establishing of correspondences between elements of the two images. These correspondences can be displayed as a two-dimensional (2D) displacement vector field. This displacement field is a low-level description of image motion which does not imply any explicit or parametric motion model, but its estimation requires smoothness or uniformity constraints [4].

Image matching methods roughly fall into two categories: continuous and discrete. Continuous approaches assume that the image intensity or a spatiotemporal derivative of intensity is conserved over time. They yield a dense displacement field, but the assumption that the intensity of the same tissue is constant from one image to the next is not correct for dynamic MR studies with contrast enhancement.

Discrete approaches proceed in two steps. First, robust features are extracted from the images: these features are supposed to carry the essential information and be insensitive to intensity variations that are not due to motion. Next, corresponding features are matched in consecutive images, producing sparsely located displacement vectors.

We aim to compare two methods, one from each category. The first method is based on the conservation of the Laplacian of the intensity, using multiscale Markov random field modeling and a pyramidal multigrid estimation strategy. The second one computes image correspondences at conspicuous points on contours, using a relaxation technique applied to edge features. Motion simulations are carried out on real data to assess their performance.

II. MOTION ESTIMATION

Continuous approach

Motion estimation can be cast as a problem in energy minimization, by modeling the displacement field as a Markov random field (MRF) [5], [3]. The equivalence of a Gibbs distribution and a MRF allows one to find a Bayesian estimate, using the maximum *a posteriori* probability criterion.

Let d represent the displacement field. The energy function to minimize, $E(d)$, consists of two terms, the conservation constraint, $E_c(d)$, and the smoothness constraint, $E_s(d)$:

$$E(d) = E_c(d) + E_s(d).$$

Let S be the set of all pixels, V a neighborhood system for S and C the set of all cliques defined over S with respect to V ,

$$E_c(d) = \alpha \sum_{s \in S} |I_1(s) - I_2(s + d(s))|^2 \quad \text{and}$$

$$E_s(d) = \beta \sum_{\{s_1, s_2\} \in C} |d(s_1) - d(s_2)|^2,$$

where α and β represent weighting coefficients, $d(s)$ the displacement vector for pixel s . I_1 and I_2 are the image intensity or any spatiotemporal derivative of the intensity. We assume the conservation of the Laplacian of the intensity.

The minimum of the multidimensional and non convex function E can be estimated using deterministic methods, which may be unable to localize the global minimum, or stochastic methods at higher computational costs [5]. We use a multiresolution method, associated with multiscale MRF models, which converges faster than stochastic methods and toward better estimates than deterministic ones [3].

Discrete approach

Edges are interesting features to be used for motion estimation because they can be relatively stable under motion, even with intensity variations. But the location of edges themselves is not sufficient for local motion estimation mainly because of the aperture ambiguity problem.

The method we use computes correspondences at critical points or nodes on image contours, such as corners and intersections. The binary images are represented by a network of nodes connected by branches. They are compared using an iterative relaxation process which assigns and updates matching probabilities between the nodes [8].

Initially, nodes are matched on the basis of the lengths and angles between connecting branches. During iterations, auxiliary matching metrics are computed to reinforce or weaken the likelihood of accepting a match between a given pair of nodes, searching for consistency in the structure and relative motion of neighboring nodes. In order to enhance the reliability of detected matches, the relaxation procedure is applied in both the forward and backward directions of the sequence.

III. EXPERIMENTAL RESULTS

Motion simulations were carried out by applying geometrical transformations to images extracted from dynamic MR studies. We selected two consecutive images from a Gadolinium-enhanced study, performed to assess the response of a femoral osteosarcoma to chemotherapy (Fig. 1) [1]. Rigid transformations (one translation and one rotation) were applied to the second image. The translation vector is $(+2, -1)$; the rotation angle is 3° and its center is in the middle top of the image. The simulated motion fields are shown in Fig. 2 and Fig. 3a.

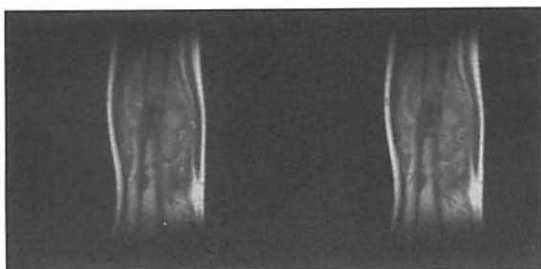


Fig. 1. The original images.

For the continuous approach, the Laplacian images were computed using the Laplacian of Gaussian filter [6].

For the discrete approach, edges were detected at the zero-crossings of those Laplacian images (Fig. 4). After thinning using Tamura's algorithm (SPIDER package [9]), the dominant points of the contours were detected following Rosenfeld's algorithm [7].

Since the true motion fields $\hat{d}$ are known, the quality of motion field estimates can be assessed through the mean square error (MSE) and the bias calculated for each component of the 2D vectors. The MSE and the bias are defined as follows [5]:

$$\text{MSE} = \frac{1}{N} \sum (d(s) - \hat{d}(s))^2 \quad \text{and} \quad \text{bias} = \frac{1}{N} \sum (d(s) - \hat{d}(s)),$$

where N is the number of computed vectors.

IV. DISCUSSION - CONCLUSION

For the translational motion, where the displacement field is uniform, reliable estimates are obtained with both methods. With the continuous approach, the estimated motion field corresponds exactly to the simulated motion (Fig. 3a).

For the rotational motion (Fig. 3b and 5b), the quality of the estimates deteriorates in terms of MSE and bias with both methods. The number of matched nodes in the discrete approach is drastically reduced. The errors and lack of matches appear especially near the center of rotation, where the displacement vectors have a small amplitude.

The difference in quality of the results between the two types of motion can be explained by the fact that the conservation of the Laplacian of the intensity is not true with rotational motion and by the fact that this effect is worsened by contrast enhancement. The contours are modified due to the intensity variations (Fig. 4).

The MSE and the bias have larger values for the second component than for the first one. This is due to a particularity of those images, which present long structures parallel to the vertical axis. Thus there is less information for local motion estimation in this direction.

The results obtained with the discrete approach (Fig. 5), which tend to be worse than with the continuous one, illustrate its difficulties:

- extracting reliably stable contours and points of significant curvature,
- estimating local motion by edge matching.

Opportunities for future work include:

- developing a cooperative approach integrating the different kinds of information;
- handling more complex types of motion;
- using the displacement fields to register the images and assessing the quality of this registration.

ACKNOWLEDGEMENTS

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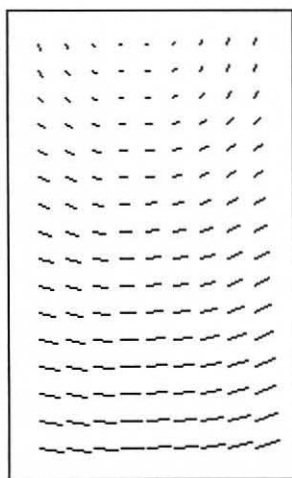


Fig. 2. Simulated rotational motion field.

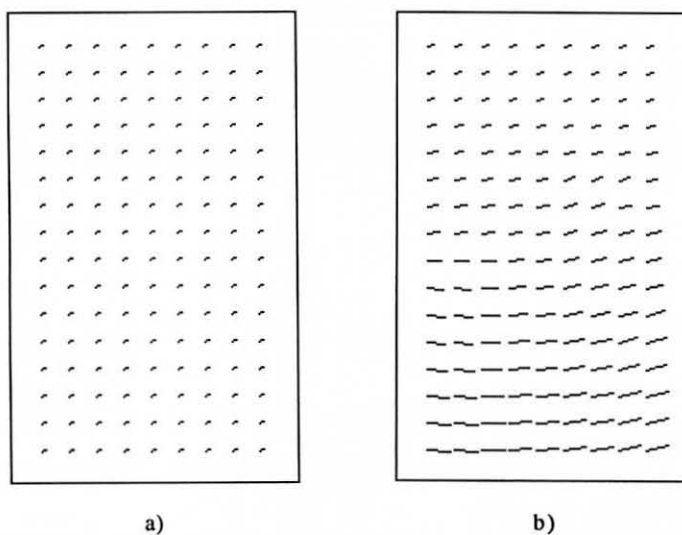


Fig. 3. Motion fields estimated with the continuous approach
 a) Translation: $MSE = (0.00, 0.00)$; $bias = (0.00, 0.00)$.
 Estimate equal to the simulated translational motion field.
 b) Rotation: $MSE = (0.51, 3.01)$; $bias = (-0.23, 0.97)$.

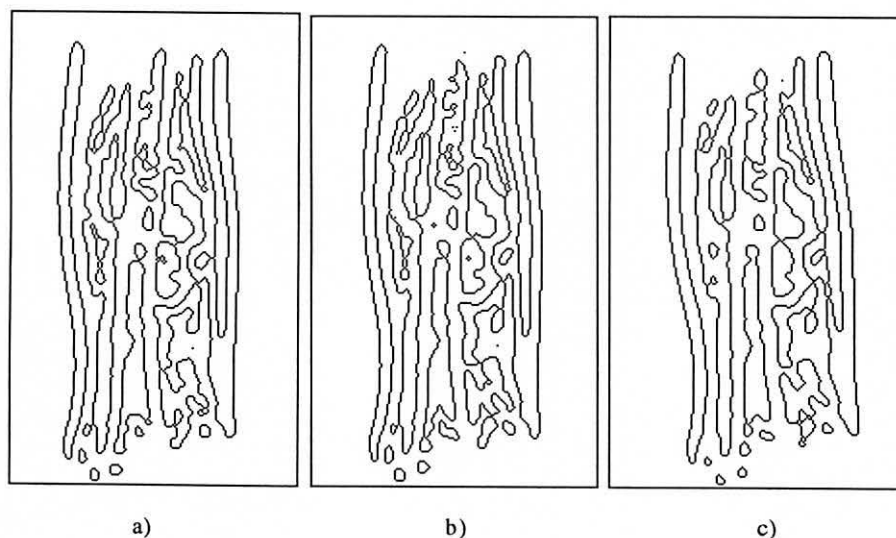


Fig. 4. Edges detected with the Laplacian of Gaussian filter.
a) First image. b) Translated second image. c) Rotated second image.

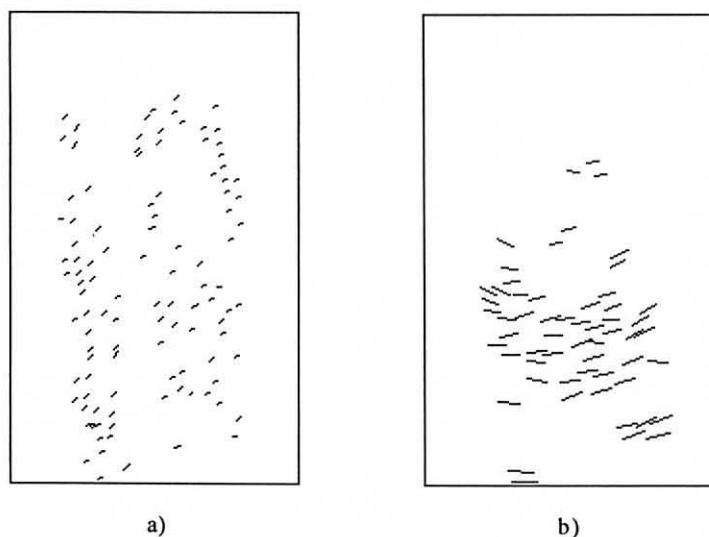


Fig. 5. Motion fields estimated with the discrete approach
a) Translation: $\text{MSE} = (0.05, 0.61)$; $\text{bias} = (-0.02, 0.48)$; $N = 108$.
b) Rotation: $\text{MSE} = (0.57, 4.33)$; $\text{bias} = (-0.05, 1.22)$; $N = 58$.

SESSION 4

**Miscellaneous /
Workstations**

Chair: Joseph K. T. Lee

A New Medical Teleworker's Terminal

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I. INTRODUCTION

One of the major promises of the Integrated Broadband Communications (IBC) is to remove the geographical constraints concerning the way in which work is organised within the community. It is of great importance to develop a technology platform which takes advantage of IBC facilities and also supports teleworking procedures via a new **Medical Teleworker's Terminal** (MTT). The proposed terminal is under implementation, according to the requirements of the RACE APTITUDE research program.

II. TELE-WORK

The use of information technology and telecommunication systems has already changed the way in which geography affects the organisation of work within society. *Telework*¹, in the most general sense, is the use of telecommunication facilities in order to enhance the performance of work. However the term teleworking is used to name situations where performance, organisation and social nature of work has changed due to the use of telecommunication facilities.

It is very important to mention that teleworking affects the social aspects of work and promises far reaching changes in society. At the level of work, relations and contact with colleagues can change and career prospects and opportunities may be different. At the level of society it can be expected that the labour market will be affected and the need for mass transportation reduced. The benefits of teleworking are clear:

- increased productivity and quality of work
- reduced energy use and road congestion for communities
- greater variety and flexibility of work

- better quality of life for teleworkers

However there has not been a wide understanding of the true benefits and potential of teleworking. The barriers to the growth of teleworking can be expressed from the point of view of individuals, companies and society. The problems can be separated into three main categories: technical, social and organisational. The intersection of the point of view of different levels of agency with the three categories of problems is shown in Table 1.

	TECHNICAL	ORGANISATIONAL	SOCIAL
SOCIETY		■	■
COMPANY	■	■	
INDIVIDUAL	■		■

Table 1.

III. PLATFORM TECHNOLOGIES FOR TELEWORKING

Generally, in order to support teleworking, a range of technologies need to be developed and made available. The term *teleworking platform* refers to networks infrastructure, operating systems and of course machine architecture.

The platform, used by teleworkers, must offer a variety of services both locally and in terms of access to their own enterprise, other teleworkers and clients. Technical solutions comprise of the commercially available products such as communication equipment, operating systems and software tools. It is of great importance, for the process of the platform's development, the applicability of such products as graphical interfaces, presentation facilities, windows toolkits etc. As a result a suitable terminal must provide an integrated environment for managing **medical facilities** using high speed communication networks².

A brief description of the major options regarding networks and machine/operating systems is important for further analysis and includes three different potential teleworking platforms which are:

- PC architecture under MS-DOS OS
- PC architecture under UNIX OS
- Workstation architecture under UNIX OS

The strengths and weaknesses of each, as the basis for a teleworking platform, are identified taking into account the below factors:

- **The advantages and disadvantages of using Windows/DOS or Unix as the operating system.**

The operating system is one of the major keys for the teleworking application and a careful study of all available choices should be evaluated. The main operating systems used with PCs and Workstations are **MS-DOS/MS-Windows** and **UNIX**. Although UNIX supports more sophisticated applications than DOS, includes more powerful tools and allows real multi-user and multi-tasking procedures, MS-DOS via MS-Windows Ver. 3.1 is also a powerful OS which offers toolkits, great presentation facilities and also supports multi-tasking applications in a significantly lower price.

- **The suitability of the underlying machine architecture (PC versus Workstation)**

Two are the key parameters regarding this factor. First, the existence of **networking capabilities** (network cards and drivers) for connection with Local Area Networks (LANs) and the **Integrated Services Digital Network (ISDN)**. Second, the existence of **multimedia products** which enable the building of the teleworking terminal. It is very difficult to separate the choice of the machine from the OS since these two are tied together. Finally two main options have been identified:

- Intel based Personal Computers - PCs (386/486)
- Workstations - WS (SUN, HP, IBM, DEC, etc)

Certainly the use of WS offers a lot of advantages. RISC technology is available and at the same time we have higher computational power, integrated **Graphical User Interfaces (GUIs)**, integrated multimedia applications, very high resolution screens and in some machines integrated **2xB+D** (2 x 64 Kbps + 16 Kbps) ISDN outlets.

But in our days, PCs technology seems to be very close to the one of WS. From one hand the **Multimedia PC (MPC)** standard is already available in the market providing PCs with built-in multimedia tools. From the other hand **LOCAL BUS** technology has dramatically enhanced graphics performance in personal computing. At the same time the latest **INTEL's** announcement **80586 PENTIUM** is certainly a challenge for users and of course teleworkers, since it is a very powerful processor available in a low price.

Finally, using the results of the analysis, which briefly described above, it was decided that the **PC/MS-DOS/MS-WINDOWS approach**, was the best choice for the teleworking platform in order to develop a suitable MTT which takes into account the specifications and the requirements of medical applications^{3,4} and at the same time makes interactive work possible and easy for the physicians.

IV. DESCRIPTION OF THE MEDICAL TELEWORKER'S TERMINAL

The proposed MTT has, at least, the following configuration:

- PC AT Compatible, 80486/66 MHz, LOCAL BUS
- 8 MBytes RAM
- 256 KBytes CACHE
- 120 MBytes Hard Disk Drive
- SVGA graphics card, 1 MB VRAM, 1024x768x256, LOCAL BUS
- 17", SVGA color monitor, 0.28 dot pitch, 1024x768 Non-Interlaced
- Serial mouse, Microsoft compatible
- MS-DOS 6.2, MS-WINDOWS 3.1

The MTT creates and maintains a windows workplace (WWP) for the teleworker (physician) which is actually his own private **virtual office** space. WWP provides access to functions which perform various types of communication like file transfer, e-mail, fax, video phone and screen sharing. The WWP contains *direct workplace objects* which actually are mouse activated labelled icons of other individual or groups of co-workers (physicians) with whom the teleworker regularly communicates. Co-workers can be added or removed from the WWP, thus activating or deactivating them.

Physicians work with a number of different media types that represent the direct products of most of their work. The produced data files may be either audio, text, video, graphics or a composition of the above media. These files are created as part of regular work tasks using applications provided from the MTT. There are three **non-interactive** methods of sending or receiving the files from co-workers: electronic mail, file transfer and facsimile. Unlike communication operations, no dialogue is required. Files are sent by dragging them from the Windows File Manager to the co-workers activated workplace. The MTT will choose a send method according to document type, co-workers capabilities and transfer properties e.g., compression, encryption, express delivery etc.

Administration objects (phone books, document groups, in trays, out trays) and communication objects (text talk, e-mail, video phone) are represented on the operations palette. Operations are activated, either by dragging icons from the palette to the workplace or by clicking the mouse over an icon engaging a menu based sub-dialogue. A phone book provides information which enable communication with an individual co-worker such postal address, telephone number, types of communication and available transfer functions. All electronic mail, facsimiles and file transfers are received through the in tray. Any item in the in tray can be viewed automatically in appropriate display. The out tray is where facsimiles, document transfers and e-mail items are held until successfully transmitted to co-workers. The physician can also group any media documents for easy transfer to co-workers via the document group icon. A single mouse click initiates a document selection and grouping sub-dialogue via the Windows File Manager. The groups are named and can be referred to at any time separately.

Indirect workplace objects are not specifically teleworking objects but regular Windows objects. The MTT exploits the existing representation of documents through the Windows File Manager rather than introducing an alternative representation and duplicating regular Windows operations. Documents are specified through a sub dialogue and are thus considered indirect objects.

Finally, the MTT provides four **real time interactive** methods of communication with co-workers: **Text talk** and **Screen sharing** are one-to-one communication facilities while **Video phone** and **White Board** are many-to-many. All are initiated by selecting the appropriate icon from the operations palette and either dragging it to an active co-worker or clicking the mouse over it and selecting an available co-worker from the phone book.

Text talk enables the physician to communicate with others by simultaneously typing and receiving text messages through a text message display. This is the same as talking to a co-worker through a telephone and has the advantage that a text file of the conversation can be saved.

Screen sharing enables the physician to send a duplicate image of an active application on his screen to a co-worker's screen, or receive a duplicate image of a co-worker's active application. As a result, physicians can work together on a medical application at the same time developing remote expert consultation procedures.

Video phone facility enable physicians to view each other on their respective computer screens as they talk.

Whiteboard is used by physicians to illustrate their ideas as they discuss them with others. The Whiteboard is displayed in all participant screens and has two different modes of operation. In the first mode, any participant can have the control and his changes to the whiteboard are queued for display. In the second mode there is a chairperson who manages the interaction between physicians with the use of a token which is given to a participant in order to allow him the *floor* (temporary control of keyboard and mouse).

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Physician Acceptance of Primary Interpretation of CT and MR Examinations on a Workstation: Implications for Future Functional Design

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ABSTRACT

Primary interpretation of images using a workstation is one criteria for acceptance of picture archiving and communications Systems (PACS). Primary interpretation of CT and MR examinations was performed on a physician workstation (DRC 106, Siemens, Iselin, NJ) for a period from two to six months. Approximately 7,000 CT and MR examinations were primarily interpreted. The quality of the images was rated the same or better than the film alternator. Interpretation time using the physician workstation was perceived to be significantly longer (20 percent to 300 percent). Workstation image interpretation time was felt to be increased primarily for three reasons: 1) window/leveling; 2) arrangement of the images prior to viewing; 3) paging through images. Forty-three percent of the physicians preferred the workstation and 57 percent preferred an alternator. Our experience with the workstation interpretation demonstrates good acceptance within several months while maintaining quality. Primary areas of functional improvement include ease of use, intuitive ways to arrange images, faster methods for doing window/level, faster ROI measurements, faster distance measurements, and easier methods to compare several studies.

INTRODUCTION

In the near future a physician workstation will replace the film alternator for primary interpretation. High quality images and an acceptable interpretation environment is necessary for this transition to workstations to occur. Ergonomic considerations must be considered in the design of the workstation.

MATERIALS AND METHODS

Primary interpretation of CT and MR examinations was performed on a physician workstation (DRC 106 [six monitors], Siemens, Iselin, N.J.). Figure 1

demonstrates several configurations. The network was Siemens PACNET via Ethernet.

Fig 1 shows the configuration. 5 MRs and 4 CTs are connected to 5 Workstations for Softcopy Interpretation. All the images will be stored on the RAID of the File Serve (ISA-Image Store & Archive) for short term and written on optical disks for permanent storage. On Laser Camera connects to the network for occasional film printing. The Workstations are equipped with high brightness Simomed-Monitors (up to 175 fL).

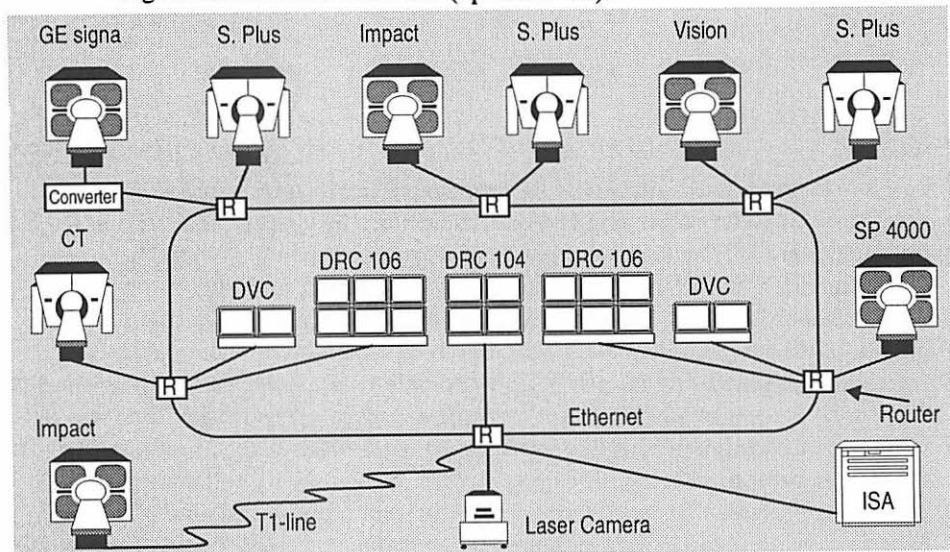


Fig 1: Configuration.

Approximately 7000 CT and MR examinations were primarily interpreted. Written and verbal comments were collecting concerning functionality of the workstation compared to the film alternator. Comments were obtained from 16 of 19 physicians interpreting images. The physicians were a mix of junior and senior staff. The start time of hanging or loading examinations, start of interpretation, end of interpretation, and time the physician completed the exam including deleting or taking down films was recorded by the interpreting physician for a limited number of examinations.

RESULTS

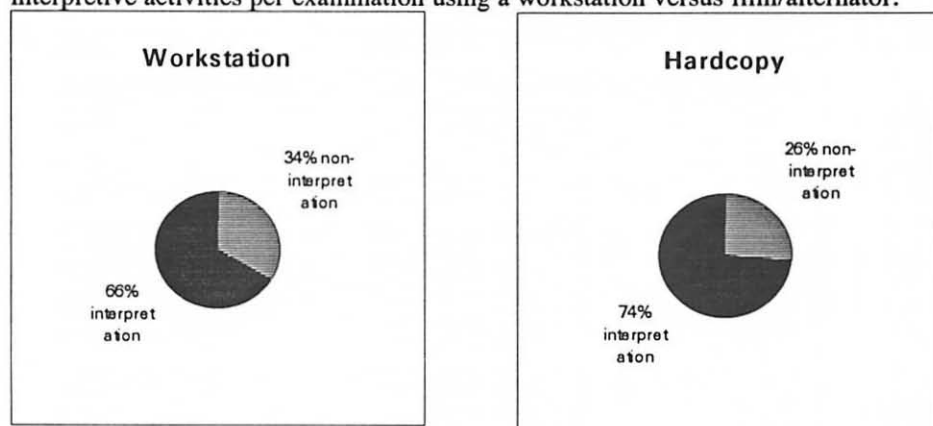
The quality of the images was rated the same or better than the film alternator. Interpretation time for the physician using the workstation initially was considered to be significantly longer (20 to 300 percent longer) than interpretation by alternator. The recent limited evaluation of interpretation time after greater than

six months experience demonstrates the opposite. Mean interpretation time for the workstation was 5:13 minutes and for film on alternator was 7:44 minutes. Quality of interpretation was felt to be the same or better on workstation than on film the alternator. The most common functions performed on the workstation were window/level, distance, ROI measurements, sequential scrolling of images, and arrangement of images. Stacking of exams from different patients was used to facilitate rapid reading, however, the present software version presents problems which in fact add time to interpretation using this feature.

Workstation image interpretation time was felt to be increased primarily for three reasons: 1) window/leveling; 2) arrangement of the images as selected individually by interpreter prior to viewing; and 3) paging through images. In spite of this forty-three percent of physicians initially preferred the workstation and fifty-seven percent preferred the alternator. This preference is changing with experience.

Table 1 shows the percent of time using the workstation and using film during primary interpretation of CT and MR images. The total interpretation time was divided into actual interpretation time (viewing images, cognition and dictation) and time in loading, arranging and taking down images.

TABLE 1 demonstrates the percent time devoted to interpretation and non-interpretive activities per examination using a workstation versus film/alternator.



Ergonomic considerations using the workstation were elicited by interview. No complaints of extraordinary eye fatigue was encountered. Orientation of monitors (6) were not considered a problem. One staff member complained of "mouse finger", tendonitis of the index finger, related to the number of mouse clicks required for image interpretation on a workstation.

No significant problems were encountered with the workstation except for the necessity to replace one video monitor which did not affect interpretation since six monitors were available. Occasional network problems resulted in the inability to transfer images to the workstation. These were software problems which have subsequently been resolved.

SYSTEM REQUIREMENTS

Based on data we accumulated from our image network and a single workstation estimated required performance based on a years' worth of CT and MR image interpretations and storage are presented in tables 2 and 3.

Table 2 shows the estimated procedure volume.

	exams/ year	image/ exam	image/ film	films/ exam	films/ year	MB/ exam	MB/ day	GB/ year
CT (4)	24,000	50	12	4.17	100,000	26	2,097	629
MR (5)	18,000	110	20	5.5	99,000	14	865	260
TOTALS	42,000	160		4.74	199,000	21	2,962	889

Table 3 shows the needed performance. The daily workload will be spread over a 17 hour period. However, for peak performance, it is assumed that 60% of the procedures will take place within 5 hours.

		CT	MR	Total
Modalities	#	4	5	9
New exams	exams/day	80	60	140
peak	exams/hour	9.6	7.2	17
peak	kB/s	17	6	11
Workstations	#	2	3	5
I/O per WS (peak)	exams/hour	15	7	10
I/O per WS (peak)	kB/s	108	30	61
Storage per WS	MB/day	2,097	576	1, 184
ISA (archive)	#			1
I/O (peak)	kB/s			197
Storage	MB/day			2,962
Optical Platters	#/day			2.47
Backbone-Load	kB/s			306

The workstation-I/O is based on receiving the according new examinations from the modalities, storing them on the local disk and forwarding them to the archive. Additionally, previous exams will be retrieved from the archive. The data

amount of the previous exams will be retrieved from the archive. The data amount of the previous exams matches around one days workload. Accordingly, the I/O of the archive is based on receiving as many new exams as sending previous exams to the workstations. To store all new exams permanently on optical disks, about 2.5 platters/day (600 MB/disk) by using lossless compression 1:2 will be needed. All the network is based on Ethernet. The accumulated backbone-load reaches 300kByte/s, which means the average utilization of 25 % during peak hours. Although the I/O of the workstation allocated for MR is relatively low compared to CT, 3 workstations are necessary, because reading MR exams is more time consuming.

DISCUSSION

Our experience with workstation interpretation demonstrates good and improving acceptance within several months while maintaining quality. Primary areas of functional improvement for workstations include ease of use, individualized intuitive ways to arrange images, faster window level capabilities, faster ROI and distance measurements, and easier methods to compare several studies. There are indications that workstations with four monitors are satisfactory for MR interpretation, although six monitors which may be advantageous when comparing current prior studies.

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Interactive Display of Computed Radiographic Images on Personal Computers

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We are investigating the hardware and algorithm requirements for interactively displaying computed radiographic (CR) images on Macintosh personal computers. Of all the digital image types commonly encountered in radiology, CR images are probably the most challenging to display because of their large size and because of the significant computational requirements for contrast and spatial frequency image processing. The target system is a Macintosh Quadra 800 with 24M RAM and a 128k cache card. The Quadra 800 uses a 33 MHz 68040 cpu. The algorithms are implemented on our 16 bit image display Macintosh application, Dr Razz¹.

Nonprocessed images are obtained from the image reader through a digital interface (DASM). Contrast processing and the 16 bit to 8 bit gray scale conversion are performed with lookup tables². The user can select the gamma table (GT A - O), the slope of the GT curve (GA), the rotation center point (GC) and the global contrast shift (GS). The base GT tables are precalculated and are stored in memory. Different values of GA, GC and GS are used to dynamically alter GT. Spatial processing is performed by unsharp masking with an optimized NxN smoothing filter using a recursive filter algorithm³. The user can select RN (kernel rank), RT (beta table) and RE (global enhancement factor).

Our preliminary benchmarks indicate that spatial processing with a different RN can be performed in under 15 seconds for a 2K image. Contrast processing can be performed in under 5 seconds if the NxN blurred image is retained in memory. We believe high performance personal computers may be useful as CR image display workstations for research, education and in less demanding clinical environments.

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Interactive Visualization of 3D Medical Image Data

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1. Introduction

Over the past fifteen years the field has progressed from coarse 3D computer graphic renderings to high quality 3D visualizations of medical image data. The rendering times for creating these images have also significantly decreased from periods of days in 1980 to tens of seconds on standard workstations in 1992. However, very limited clinical use has been made of 3D renderings at this time. Probably the most significant reason for this is the lack of interactive user control of the renderings. 3D visualizations hold great promise if the user can interactively segment and classify the data, and interactively choose viewpoint and rendering parameters to optimally visualize information present in the datasets.

In 1993, for the first time, commercially available workstation hardware is capable of real-time 3D volume rendering of medical image data in a clinically useful fashion. Our experience at UNC using non-interactive and interactive renderings indicates that three primary elements are necessary for a clinically successful real-time interactive volume rendering tool: 1) the user must be able to interactively classify the data to visualize difficult to define "surfaces", such as soft-tissue/soft-tissue boundaries in the chest and abdomen, as well the more easily defined boundaries such as bone/soft-tissue and skin/air; 2) the user must be able to interactively and conveniently choose the parameters determining the rendering of the scene (i.e. arbitrary viewpoint, zoom, lighting conditions, rendering algorithm); and 3) the ability to cut away the volume to reveal occluded portions of the anatomy (using cutting planes or sculpting tools).

A few prototype very high speed rendering engines have been developed that support realtime volume rendering, including Pixel Planes¹, and the Princeton Engine². While these systems have allowed research into realtime 3D volume rendering, there have not previously been commercially available systems supporting the speeds necessary for interactive volume rendering. This paper will concentrate on the two new commercially available systems, the Denali from Kubota Pacific Computer Inc. (Kubota) and the Reality Engine based systems from Silicon Graphics Inc. (SGI), which we found capable of real-time, clinically useful, volume rendering.

The second section of this paper provides background on 3D volume rendering and its application to medical imaging. The third section of the paper will discuss several aspects of realtime volume rendering: hardware requirements for realtime volume rendering of medical image volumes; descriptions of Denali and Reality Engine systems; and, benchmarks of these two systems and analysis of their performance. The

fourth section describes specifics of realtime algorithms. Finally, the fifth section of the paper discusses the preliminary results of using our realtime volume rendering application, SeeThru, for clinical cardiothoracic surgery planning at UNC Hospitals. Due to space constraints, significant portions of sections 3 and 4 have been left out of this version of the paper. Contact the author for a complete version.

2. Background

As computers with video displays became accessible to researchers during the 1970s and 1980s, people began to experiment with displaying medical image data on them. Initially, most work was to display collections of individual 2D images from film on video displays, especially images from the newer, digital modalities (nuclear medicine, CT, MR, PET). As computing power increased, developments in the field of computer graphics led to the design of algorithms that would depict 3D structures on 2D display screens so that the human observer would have a sense of the 3D scene. The appearance of a 3D scene from a static 2D image was accomplished using visual cues such as occlusion, perspective, shading, and stereo (when using stereo display and glasses). These results were then applied to medical image data that could be acquired as a 3D volume. Initially, this was mainly sets of parallel 2D slices in 3D space, which were then treated as a 3D volume sample. More recently, acquisition techniques have been developed allowing for the acquisition of actual volumes samples. In either case, these sets of volume elements, usually referred to as voxels, make up a 3D volume that can be displayed using computer graphic techniques on a 2D screen.

The original methods used to display the 3D scene as a 2D image on the video display are now referred to as *surface rendering* methods. These methods required the determination of a surface of interest from the 3D volume. Identifying the surface of an object of interest required generating a contour on each 2D slice. This meant hand contouring the object on each slice, or using image processing techniques (thresholding, region growing/dilation) to semi-automate the process, and then following this by a method to create a polygonal surface from the contours³. These methods had two significant disadvantages. First, they required time consuming contouring steps, often requiring highly skilled medical personnel to do the contouring and follow-up editing. Second, they drastically reduce the information content of the study by making a binary decision as to where surfaces lie, thus reducing the dataset from a 3D volume of density values, to a list of surfaces. Reducing the 3D volume to a list of polygonal surfaces creates a very compact representation, that could be rendered fairly quickly on graphics workstations, which generally had hardware support for rendering polygonal type objects.

In the last several years, as computer power has increased and hardware prices have declined, experimentation with actually rendering the entire data volume has become possible. Rendering directly the entire volume without the intermediate step of defining surfaces is generally referred to as *volume rendering*. Volume rendering methods model the voxels as objects in space and calculate the interaction of light with these objects as seen from the observer's viewpoint. The treatment of voxels as different types of objects (point samples, blobs, cubes, etc.) with different possible reflectance and scatter characteristics has lead to the creation of many different volume rendering techniques. A general discussion of volume rendering can be found in

Drebin⁴, and a recent survey of volume rendering techniques applied to medical imaging can be found in Yoo⁵.

The 2D images representing 3D volumes are even more realistic to the observer if they can be interactively rotated in space via user control due to kinetic depth effect.^{6,7} Since this requires at least 5-10 frames per second update rates to maintain the visual precept of a single object in continuous motion, current workstations have not been capable of realtime volume rendering. However, as computation times have decreased to seconds and minutes, the *cine* presentation has been increasingly popular. This involves the precalculation of multiple angles of view along a rotation of the object. These precomputed individual views are then displayed as a cine sequence over the predefined rotation, and this provides kinetic depth effect benefits similar to those of interactive control of the rotation. Currently, as seen at RSNA 1993, commercially available presentations generally support: non-interactive high quality 3D image renderings, pre-computed cine presentations of low and high quality renderings, near-realtime presentations of less complex volume rendering methods such as MIP, IsoSurface, and rendering by intermediate processing to polygonal surfaces via Marching Cubes or similar algorithms. A very significant development occurred in 1993. For the first time, commercially available off the shelf workstation hardware is capable of realtime high quality volume rendering. The two commercial systems supporting realtime rendering are the Kubota Denali and the SGI Reality Engine.

3. Realtime Volume Rendering Systems

The requirements of a realtime volume rendering systems can be estimated for an average CT study of 512x512x64 (2^{24}) voxels. In order to render the image data, the volume renderer essentially has to sample at the resolution of all the voxels, or perhaps slightly finer. When sampling, the desired (x,y,z) position at which the volume should be sampled generally does not fall directly on existing voxels, and must be properly estimated from its nearest neighbors. This requires performing an operation referred to as a trilinear interpolation. The simplest 3D neighboring sampling requires accessing each of the 8 adjacent neighbors and results in performing about 23 additions and 12 multiplications per sample. Finally, in order to have interactive rendering we need at least 10 frames a second. Thus a lower bound estimate of required operations would be

$$2^{24} \text{ samples} * \text{about } 30 \text{ low level operations} * 10 \text{ frames second}$$

or about 5 Giga-operations per second. The best measure of speed is the resulting number of frames per second for a certain rendering method. Because this depends on several variables, it is often more convenient to use the number of 3D trilinear interpolations per second that the renderer can perform to compare systems since this is the basic common operation. Thus to achieve ten frames per second for the above CT study a system should be capable of approximately $2^{24} * 10$, or 160 million trilinear interpolations per second.

The major problem in accomplishing this goal is the size of the dataset to be held in memory (2^{24} for our CT example), and the rate which it must be sampled. Most methods that have attacked this problem have done so by some form of parallelization, either in screen space or in image space. This essentially divides the problem into smaller pieces that can be rendered more quickly, reducing the size of the problem. The tradeoffs are the partial redundancy in copies of the image voxels and communication

between subparts during rendering, especially during the recombining of information. As computer power increases and prices drop, at some point we would expect to see direct hardware support for holding an entire volume of data as a single entity and rendering it directly. One method of accomplishing this is utilizing the 3D texture map memories on high end graphics engines. These 3D texture memories were developed to allow texturing of 3D objects in addition to 2D ones, to further support the needs of highly realistic rendering of synthetic scenes. Importantly, however, these 3D texture memories are essentially the 3D volume resampling mechanism needed for directly rendering the entire volume. The sampling of the volume from texture memory is accomplished by sampling planes through the entire volume texture perpendicular to the viewpoint, and compositing the results of each sampled plane to create the final 2D image. Because the planar sampling from texture memory and the compositing have hardware support, the renderings can be accomplished in realtime. We refer to this technique as *planar texture volume sampling*, and a description of our algorithm as implemented on the SGI Reality Engine is given in section 4.

3.1 Kubota Denali

The Kubota Denali is comprised of Transform Engine Modules (TEM) and *Frame Buffer Modules* (FBM) modules. The Denali system supports having up to 6 TEMs and up to 20 FBMs. The TEMs perform the first stages of the graphics rendering pipeline, geometry transforms, lighting and shading calculations, and scan conversion. The FBMs are responsible for per pixel operations. To achieve realtime performance the full volume is partitioned into pieces which are stored on separate FBMs for parallel processing. The pixel engines on each FBM support 600,000 trilinear interpolations per second, allowing a maximally configured Kubota (20 FBMs) to achieve approximately 12 million trilinear interpolations per second. The Denali has direct support for manipulating and rendering volume datasets in the Kubota Volume Extension to the Kubota X server. At the time of our benchmarking the system in October 1993, the Kubota Volume Extension supported projection summing (maximum intensity projection, minimum intensity projection, and ray sum projection) and IsoSurface rendering methods. In follow-up discussions with Kubota, they have indicated that opacity based compositing methods are under development.

3.2 SGI Reality Engine

The SGI Reality Engine currently supports the largest 3D texture memory size. On the Reality Engine volumes can be held in the 3D texture memory on the raster manager (RM) boards. Parallelization of work can be done through the use of multiple raster manager (RM) boards, each of which has its own independent copy of the entire texture memory. The Reality Engine supports 1, 2 and 4 board configurations. Our initial work has been done using the RM4 boards which hold 4 Mbytes of texture memory data. In January of 1994, SGI released their RM5 boards which hold 16 Mbytes of texture memory. We benchmarked a single Reality Engine RM4 board at approximately 37 million trilinear interpolated samples per second from the 3D texture memory, and the two raster board system at twice that amount. Using four boards should quadruple the single board rate. We have implemented a planar texture volume resampling method that supports several rendering methods including MIP, Xray Projection, opacity-based compositing, and gradient-based compositing. The Reality Engine allows several different configurations of texture memory, leading to many different possible rendering combinations. Under our current implementation, the

rendering times are all equivalent because the size of information stored and manipulated for each voxel is 16 bits, so for the benchmarks we used the opacity based method.

Only the portions of the Denali and Reality Engine architectures pertinent to realtime volume rendering have been described. The Kubota system is described more completely in their technical white paper documents,^{8,9,10} and their realtime volume rendering is more completely described by Guan.¹¹ A technical description of the SGI Reality Engine is available as a technical report,¹² and the upcoming paper¹³ will describe the application of the Reality Engine to volume rendering. Additionally, more in-depth discussions of realtime volume rendering architectures, such as Pixel Planes,¹ Pixel Flow,² and Princeton Engine,^{2,24,25} can be found in computer graphics literature. Finally, both the Pixel Planes (under Division) and the Princeton Engine (under David Sarnoff Labs) projects are also being turned into commercial products.

3.3 Benchmarks

Complete details of the benchmark results, experimental protocol and analysis can be found in the complete paper.²⁶ As a summary, we compare the standard process we have found useful clinically: rendering a 256x256x32 dataset using opacity blending and trilinear sampling to a 512x512 window. This choice of window size, combined with choosing a zoom of 0.70 on the Reality Engine yielded the most similar resulting image size, as well as the most similar amount of sampling (image quality). On the Kubota we substituted MIP renderings for the opacity method. With these settings, the Kubota can achieve marginal realtime speeds (4.92 frames/sec) when rendering. It also has the ability to render larger datasets (such as our example 512x512x64 study), but at less than realtime speeds (2.30 frames/sec). The Reality Engine with one raster board can achieve between marginal and good realtime rates (7.86 frames/sec), and with two raster boards it can achieve slightly better than good realtime rates (11.39 frames/sec).

4. Realtime Volume Rendering using Volume Texture Memory

We have previously published the algorithm for planar texture volume resampling, named *Voltex*, and described an implementation for rendering volume datasets in realtime on the SGI Reality Engine¹⁵. An updated description of the algorithm can be found in the complete version of this paper.²⁶ More recently, similar algorithms have been described by the technical staff of both Kubota¹¹ and SGI¹³; additionally, example volume rendering software is provided with those systems.

5. Clinical Experience using *SeeThru* Visualization Application

SeeThru@ is an application developed in the Department of Radiology at UNC for visualizing 3D medical image volume datasets. It is based on the *Voltex* rendering algorithm. Previous work has been done in visualizing surfaces that are easily definable, including bone/soft-tissue,^{17,18} contrast in vessels in angiographic studies,^{19,20} and skin for plastic surgery. *SeeThru* was developed to test whether we could effectively address the problem of visualizing difficult to define surface boundaries such as soft-tissue/soft-tissue interfaces. Our previous experience using Pixel Planes and the SGI led us to believe this was feasible if we could provide

effective interactive control of three things: the parameters of the rendering, the parameters of viewing, and tools for cutting or cropping away parts of the study. After some experimentation in early 1993 using SeeThru on phantoms and clinical test cases, we made the tool available for clinical use in the fall of 1993. At this time a wide range of pilot cases has been done in the chest, abdomen, head and breast using both CT and MRI. Our most successful effort to date has been in thoracic surgical planning using spiral CT contrast studies and SeeThru to visualize the internal soft-tissue structures of the patient.²¹ The overall result is that clinicians actively request and use the SeeThru visualization tool, while they have not utilized existing clinical 3D applications on the scanner (cine loop and static MIP projections), or earlier research efforts (non-interactive high quality pictures). In our initial six months of clinical experience we have learned several important things about our rendering tool, and also about the visualization task. These are summarized below.

Information learned about choice of rendering tool and parameters

- Effective and easy to use computer human interface tools are required for manipulating the volume. The major operations are specifying rotations and cutting/clipping planes. For rotation, for example, user preference seems to be (first to last): using passive interface props²² where actions on a 3D prop directly correspond to actions on the 3D screen object; using virtual sphere interface²³ where 2D mouse movements kinesthetically correspond to rotations of the 3D object on the screen; specifying motions via unbounded dial knobs; specifying motions via slider bars.
- Classification via opacity based compositing control eliminates need for segmentation in many of studies.
- Interactive segmentation tools will still be needed to visualize objects that cannot be isolated by classification and/or cutting; additionally, clearly segmented objects would improve the visualization in some types of studies.
- Opacity based rendering has provided the best visualizations to date. Especially important is the ability to interactively classify to see certain elements of the volume.
- Gradient based methods are not effective at finding, and visualizing surface for soft-tissue/soft-tissue interfaces because of lack of clear well defined boundaries.
- An important addition would be to have control over light source. Currently, the light source is fixed in relationship to the volume. This is to reduce storage and processing cost by not storing the normal at each voxel location (i.e. this would require two extra bytes to properly store 3D gradient, which would at least halve the current performance).
- Stereo may improve performance; however, other studies have shown that given the kinetic depth effects of interactive rotation, stereo does not significantly enhance the 3D perception⁶. Often, though, the clinician may want to concentrate on a single view, rather than have the object in motion; thus, this scenario may

benefit from a stereo presentation. We have not tested using stereo at this time because it halves the frame rate, and reduces the resolution of the y axis.

- Realtime rendering of the volume makes exploration possible. This is often important in trying to find a visualization to answer a specific clinical question. Often, a 3D static visualization or cine loop failed to answer the clinical question, while the ability to interactively find the best, or sufficient visualization that allowed finding a satisfactory answer to the clinical question. One initial drawback of this is that, unless users are provided excellent computer human interaction methods, they may spend tens of minutes searching out optimal visualizations, compared to the seconds to few minutes generally required by our expert users.

Information learned in using realtime visualization clinically

- Experienced radiologists do not benefit as much except for complex or uncommon anatomy, as they are well trained at reconstructing the expected anatomy in 3D from 2D cross sections.
- Other people, without significant experience at reconstructing 3D from 2D slices, seem to benefit significantly from seeing and interacting with the 3D visualization. Surgeons seemed to be especially comfortable using the 3D visualization tools, perhaps because it is closely tied to their clinical experience in manipulating the true 3D objects (i.e. the patient's body).
- In addition to using the 3D visualization for understanding the anatomy, the surgeons made significant use of the 3D representation as a model to communicate with other surgeons and medical staff in planning the operation.
- The typical scenario using SeeThru to assist in surgical planning was to classify the volume to see appropriate areas of interest; then to cut away and rotate the volume to get the best view; then cut back and forth through the 3D volume to see interior objects better, especially cutting in and out from an angle similar to the planned surgical entry.
- We found that being able to present a separate window with multiplanar reformatting information to be more preferred than to present this data on top of a volume slice. Presenting the 2D slice (intensity windowed version of density values) on the 3D volume (rendered to realistically simulate physical lighting model) takes away from the 3D perception of the object, and does not present the 2D slice at high resolution. Also, the addition of separate multiplanar 2D views essentially provide a combination 2D and 3D presentation environment combining views depicting both the 3d object and 2d density presentations. Since the 2D views support interactive access to all views from that angle, this combination presentation may serve as a replacement for seeing tiled presentations of the images on the lightbox or monitor, as they are commonly clinically presented at this time.
- The ability to conveniently bring up the study immediately, without preprocessing steps, and the ability to see and interact with the volume in 3D to visualize

information not seen on 2D slices were the reasons clinicians gave for using SeeThru.

- Radiologists and clinicians generally preferred not to use successive refinement because of constant changing of the objects due to the refining made comprehending the 3D nature of complex objects even more difficult. Thus, for medical imaging, while successive refinement may be useful in helping the user keep track of global position while manipulating the object, it was detrimental to comprehending the object in 3D, which was the main objective of the medical users.

6. Acknowledgments

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The Visibility Control: A Simplified Interface for Selecting Window Width and Window Level Settings for Radiographic Images

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Window width and window level controls are present on most consoles and workstations that display extended range gray scale radiologic images. However, inexperienced users often encounter difficulty when using these controls because: 1.) most of the possible window width and window level settings do not result in an optimal image, and 2.) the relationship between these settings and the visibility of desired image features is not readily apparent.

We have developed a simplified window/level user interface that utilizes a single control -- the visibility control -- that adjusts both the window width and window level settings. As the control is adjusted across its range, the window level setting varies from the lowest to the highest setting. At each position of the control, each window level is matched with a predetermined optimized window width setting (Figure 1). Therefore, all positions of the visibility control result in an acceptable image. When the pairs of window width and window level settings are plotted, a characteristic "V" shaped curve is formed (Figure 2). Furthermore, there is an orderly progression of image features as the control is adjusted. For example, in a CT scan of the chest, the lungs, soft tissues, mediastinum and bones are optimally visualized in sequence as the control is changed.

We have implemented the visibility control on an application for Macintosh computers and on RS-6000 and Sun 3/260 X-windows work stations. We believe this control is ideally suited for image display workstations in clinical environments utilized by inexperienced users.

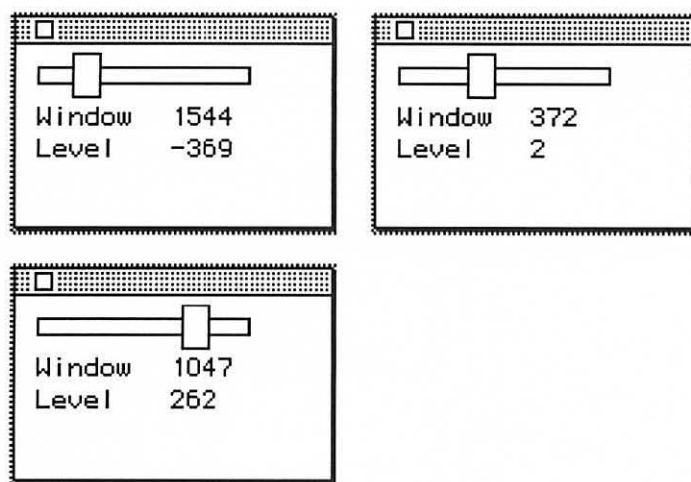


Figure 1. The visibility control as implemented on a Macintosh computer. A (top left). Lung window/level settings. B (top right). Mediastinum settings. C (bottom). Bone settings. Note how changing a single control affects both window and level settings.

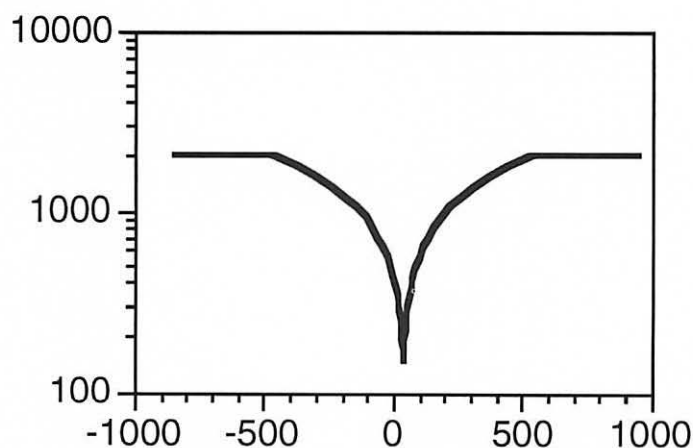


Figure 2. Visibility control settings. A plot of window settings (y-axis, logarithmic scale) and level settings (x-axis, linear scale).

SESSION 5

Image Processing

Chair: Sridhar B. Seshadri

Accurate, Model-Independent Determination of Cardiac Volumes

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Introduction

The purpose of this study is to examine the accuracy of left ventricular volume measurement using fast-acquisition cardiac magnetic resonance imaging (MRI) in conjunction with automated border detection, partial volume correction, and the novel integrated contiguous stack (ICS) method for volume determination.

Techniques for determination of left ventricular volume fall into two broad categories: model-based and model-independent [2]. Model-based techniques assume that left ventricular shape conforms to a specific geometric model. A relatively small number of images are acquired from which measurements are made. These measurements can be thought of as model parameters. The pitfall in the model-based approach is that disease, such as aneurysm, may violate the geometric assumptions implicit in the model used, thus leading to significant error. Model-independent cardiac imaging on the other hand images the entire region of interest, typically as a stack of contiguous cross-sectional slices. Here abnormal cardiac geometry is not a confounding factor. However, for model-independent methods to be practical, it must be possible to acquire many images in reasonably short time. The effort required for image segmentation and measurement can also be an important factor. Fast MRI techniques [1] such as segmented turboFLASH and echo-planar imaging (EPI) have reduced imaging times from minutes for "conventional" MRI to seconds (turboFLASH) or even milliseconds (EPI). These methods not only make it possible to acquire large numbers of images within the duration of a typical clinical session, but can also reduce artifact due to patient respiration and other motion. The real-time automated border detection (segmentation) used in this study reduces both processing time and the interobserver variability associated with hand-traced borders.

For contiguous stacks, it is most reasonable to orient imaging planes (slices) either perpendicular to axes in the magnet coordinate system or perpendicular to cardiac axes. In the former case, slices are typically obtained in the transverse (TRA) orientation, perpendicular to the bore of the scanner; for the latter, the best choice of imaging planes is perpendicular

to the long axis of the left ventricle. We refer to the latter orientation as "cardiac short axis" (CSA). It is typically not possible to align the patient so that magnet and cardiac axes coincide. In the general case, two single-plane angulations (leading to "double-oblique" imaging) are required to rotate the imaging plane to cardiac axes. Images acquired in the TRA orientation are subject to partial volume effects due to obliquity, and the problem of defining basal extent. These issues can be important, as not all echo-planar MRI scanners are capable of double-oblique EPI. In this study we acquired image stacks in both TRA and CSA orientations.

Methods

Normal human volunteers (n=10) and Yorkshire pigs (n=6) were imaged using a 1.5 Tesla echo-planar whole body scanner (Siemens Medical Systems, Erlangen, Germany). Images were acquired with ECG-trigger and breath-hold for all studies.

Yorkshire pigs ranging from 30 to 50 kg were anesthetized with 1.25% isoflurane and mechanically ventilated. Following a series of scout images to determine orientation of cardiac axes, three turboFLASH ciné series were obtained in the following orientations: mid-level CSA, four-chamber long axis and two-chamber long axis. Echo-planar stacks in CSA orientation were obtained at diastole. Imaging parameters are given in Table 1. Upon completion of all imaging studies, animals were sacrificed by intravenous injection of saturated solution of KCl resulting in diastolic arrest. The hearts were excised and casts of left ventricle were made using five-percent agar solution. Volumes of casts were measured by fluid displacement.

In human studies, the same sequence of scout and turboFLASH ciné acquisitions were used, after which EPI stacks in both CSA and TRA orientations were obtained at systole and diastole.

Sequence	TR(ms)	TE(ms)	Thk(mm)	FOV(mm)	Matrix
Ciné	30	10	5	250	64×128
Segmented turboFLASH	130	7	3	300	130×256
EPI	n/a	28	3	360	64×128

Table 1. Magnetic resonance imaging parameters.

Images were analyzed on a SPARC2 workstation (Sun Microsystems, Mountain View, CA) using automated border recognition/segmentation software (Unified Medical Systems, Brookline, MA). Segmentation follows two mouse-button clicks: the first click initiates a border, the second selects the object and automatically computes statistics (area, circumference, moments, signal mean and variance). The border determined is the optimal

discriminant between pixel populations in the neighborhood of the first click. The entire process occurs at interactive speed in well under a second. The full depth of source pixel values are used; the computation is unaffected by display depth or choice of window and center settings. Border definition can be automatically propagated through the entire stack, or local updates can be made on a slice-by-slice basis. Measurements are displayed graphically and written to a text file.

Left ventricular volumes were calculated using a biplane area-length formula ($V=8\pi A_{4c}A_{2c}/3L_{\min}$) from two- and four-chamber long axis images [2]. CSA and TRA stack volumes were computed using partial volume correction and the "integrated contiguous stack" (ICS) method. ICS integrates a polynomial fit to the cross-sectional area values; this is depicted by figure 1. Given the reasonable assumption that the function representing the areas is continuous, ICS allows control of the maximum approximation error over the region of interest by selection the order of the approximating polynomial. Partial volume effect (figure 2) arises when a cross-section is obtained using a plane oblique with respect to the barrel of the left ventricle. This produces bordering "grey" voxels in our EPI images, where myocardial signal is "bright" and bloodpool is "dark". Partial volume correction computes bordering-voxel intensity as a fraction of the difference between bright and dark. This method provides subvoxel accuracy [4].

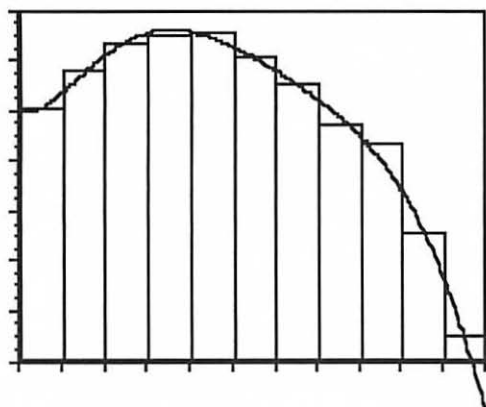


Figure 1. The rectangles represent cross-sectional slices. The curve is a sixth-order polynomial, P fitted to the midpoints of the slices. Volume by ICS is determined by integrating P over the extent of the left ventricle.

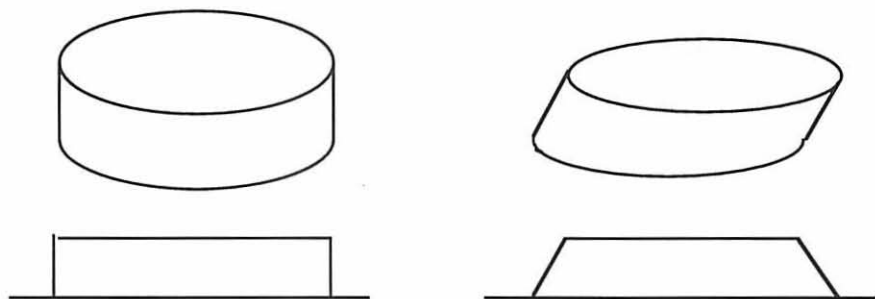


Figure 2. Partial volume effects. (Left) Projection of slice perpendicular to long axis of right cylinder produces sharp profile. (Right) Projection of oblique slice causes "spread" of signal intensities.

Results

There was excellent correlation between porcine left ventricular volumes measured by CSA stack and by cast ($r=0.99$). There was significant difference between biplane area-length volume and cast volume ($p<0.05$), as two of the six pigs had left ventricular aneurysm. In particular, one pig with aneurysm had a CSA-measured diastolic volume of 43.7 ml, compared to 64.5 by area-length. Actual diastolic volume determined by cast was 43.3 ml. The aneurysms produced both morphological and functional abnormalities (figure 3). Excluding pigs with aneurysm, there was no significant difference between cast and biplane volumes.

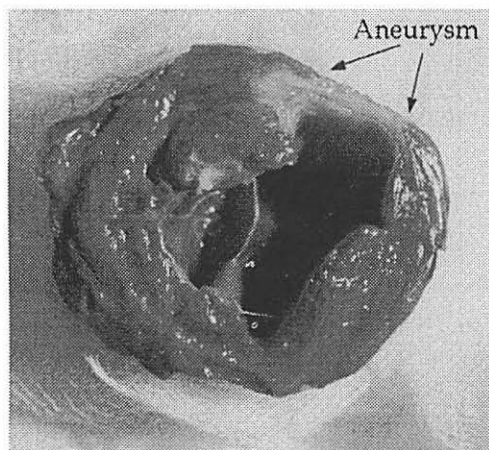


Figure 3. Mid-level cardiac short axis (CSA) view of excised porcine left ventricle with aneurysm. Aneurysm was a result of chronic ischemia produced by gradual occlusion of the coronary artery responsible for supplying the afflicted region.

In normal humans there was good correlation ($r=0.95$) between volumes determined by CSA and TRA stacks. There was lower correlation ($r=0.65$) between CSA and biplane volumes, but differences were not significant. Examples of echo-planar images of normal left ventricle at diastole are shown in figure 4.

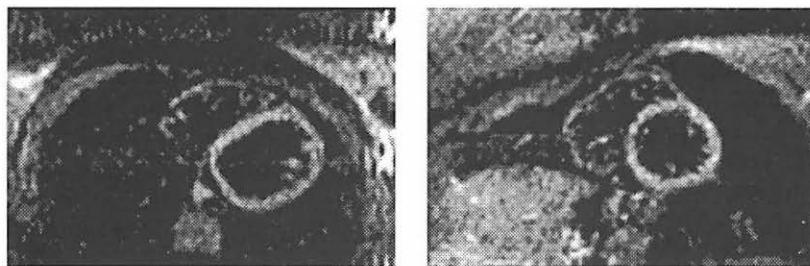


Figure 4. Dark-blood double oblique echo-planar images of normal human heart at diastole. A transverse-plane (TRA) cross-section is shown at left, cardiac short axis (CSA) at right.

Discussion

Left ventricular volumes determined by integrated contiguous CSA stack agree well with cast volumes. In the absence of infarction, model-independent CSA stack and model-based biplane area length methods both produce accurate results. In the presence of infarction however, biplane volume error can exceed fifty percent, while CSA stack volumes remain accurate.

Results from human subjects indicate that there is good agreement between transverse and cardiac short-axis ICS (stack) volumes when attention is paid to extent of the base of the left ventricle and when partial volume correction is applied to account for obliquity of slices relative to cardiac axes. Polynomial fit to the measured slice areas allows control over the maximum difference between the approximating polynomial and the underlying curve of cross-sectional areas through selection of polynomial order. Integration of the approximating polynomial provides the ICS volume estimate. When selecting polynomial order, there is the usual tradeoff between desirability of fidelity to measurements and the peril of overfitting to poor "wild point" measurements. For the cases we studied, there was no significant benefit in using polynomials of order higher than six.

In conclusion, for normal left ventricular shape, model-independent stack methods and geometric model-based methods both produce accurate estimates of ventricular volume. Integrated contiguous stacks in the CSA orientation provide the best measures of volume; with partial volume correction transverse stacks do not differ significantly. If obtaining the number of images required for stacks is difficult, due to lack of fast MRI capability or low patient tolerance, for example, area-length methods can be used with confidence in the absence of abnormal cardiac geometry. In the presence of abnormal ventricular geometry, volume error with area-length methods can be substantial and significant.

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Quantitative Metrology of Coronary Arteries with an Integrated Coronaries Measurement (ICM) System

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1.0 Introduction

Since the technique of selective coronary arteriography has been described over three decades ago, the production of high quality coronary angiograms has dramatically improved. Despite enhanced image acquisition and display, **the basic analysis of coronary arteriograms has generally remained unchanged**. The vast majority of clinical catheterization laboratories continue to rely on visual estimates of percent diameter stenosis to quantify the severity of artery disease. Unfortunately visual estimates of lesion severity are neither reproducible nor accurate [1].

Computer-assisted procedures can improve quantitative analysis of coronary arteriograms in two respects. First, automation reduces the interobserver and intraobserver variation for determining the severity of coronary artery stenosis [1,2]. Second, efficient computer algorithms are essential to analysis procedures of high computational demand, such as determination of coronary blood flow from sequential frames of arteriograms [3,4] and reconstruction of three-dimensional vascular structures from biplane angiograms.

Two different strategies can be employed for identification of vessel contours, i.e. **scanning** and **tracking**. **Scanning** is typically a two-pass operation. There, the user begins by indicating the proximal and distal end of the vessel segment containing the stenosis, and the algorithm estimates an initial centerline. The data are resampled along straight lines, denoted scanlines, perpendicular to the local centerline directions, and initial contours of the arterial segment along the scanline are determined. Contour definition is performed by computing the first and second derivative functions of the scanlines. The contours along the segment are defined by the application of a so-called minimal cost criterion to a weighted sum of the first and second derivative functions. The minimal cost technique takes into account all the intensity and derivative information along the arterial segment, and the contours are obtained by searching the cost matrix for a minimal cost path. This technique minimizes the effects of intervening structures, such as crossing vessels, since contours are not determined by individual scan lines but all scanlines in composite. The algorithm has shown to be fast and robust [4], but has a number of disadvantages as reported by the designers themselves [5]. First, only one point per scanline will be selected by the algorithm. This assumes that every scanline will be

more or less perpendicular to the edge of the coronary artery. Especially when the coronary artery is irregular within an abrupt lesion, this condition is not satisfied. By the limitations of the algorithm only one point will be selected on each scanline, even when, in reality, more points of the scanline should be included in the edge. Another disadvantage of the minimum cost algorithm is the way the grey values are used. Since the image is resampled and derivatives are only calculated along the direction of the scanlines, edge information perpendicular to the scanline is discarded. In case of an irregular contour, the edge runs parallel to the scanline, as a result, this edge is totally ignored by the algorithm. Depending on the position and direction of the scanline, other, less prominent edges may have the lowest cost values, thus leading to falsely detected edges and to a larger variability in the contour detection techniques. It is also well known that the edge detection based on the weighting of first and second derivative functions (50:50) overestimates vessels in the small diameter range (< 1.5 mm). To improve the accuracy in the small diameter range, deconvolution technique based on the system transfer function or modification of the kernels for the computation of the first and second derivative functions have been proposed and reported, but to our knowledge, the details of the algorithms have never been “clearly” reported.

Tracking operation also begins at an a priori known position on the image plane. In a single-pass operation, extraction of the image features and recognition of the vessel structure are simultaneously accomplished by exploiting the continuity properties of the vessel. In the proposed algorithm, data obtained from phantom studies based on different systems and different clinical conditions are used dynamically by the edge detection mechanism to compensate for the different pointspread functions between the different diameter ranges of vessels.

2.0 Algorithms for tracking and edge determination

We have developed and implemented algorithms for the identification and quantitation of vessel contours in coronary arteriograms based on a tracking approach proposed by Sun [6]. The algorithms consisted of an extrapolation-update process which was guided by a matched filter. The robustness and accuracy of tracking are improved by exploiting the following continuity properties of a blood vessel:

- 1- Continuity of position : the centerline and edge pixel positions vary continuously along a vessel segment on the image plane.
- 2- Continuity of curvature : the vessel direction varies continuously along a vessel segment.
- 3- Continuity of diameter : the lumen width varies continuously along a vessel segment. However, abrupt changes of lumen width or irregular shapes of lumen cross section may be observed at a stenotic section.

4- Continuity of density : although the image background may present abrupt changes in density, the dynamic range of the cross-sectional density profile (the vessel) varies relatively continuously along a vessel segment.

The optimal design of a tracking algorithm would require the a priori information regarding the probability distributions and spatial frequency characteristics of position, curvature, diameter, and density functions. The problem is further complicated by the variation in imaging quality, resolution, and calibration process. While such information is unavailable at present to facilitate an overall optimal design, a combined mathematical and heuristical approach are used here.

The tracking algorithm developed has an extrapolation-update structure similar to that of a Kalman filter. Given the estimation of centerline, width, and orientation for the current incremental section of the vessel, the next incremental section is extrapolated along the current vessel direction. A matched filter locates the next centerline position based upon the vessel cross-sectional density profile at a look-ahead distance away. In the update process, the vessel direction, width, and centerline position for the next incremental section are determined. **The look-ahead distance and the search window size are adapted to the current vessel width**(a small vessel is more likely to exhibit abrupt changes in its orientation than a large vessel is). The tracking process is actuated by the operator's definition of the start and end points of the coronary segment to be analyzed.

The two edge points are identified by searching for the roll-off point at a density level related to the signal (the vessel) and the background. Because the roll-off point is determined by an averaging process and using information of the entire density profile, this edge detection scheme should be less sensitive to high frequency noise than a maximum slope method which employs a differentiation process. Furthermore, the threshold or the ratio between the vessel and the background is dynamically adjusted to the actual size of the tracked vessel based on the data obtained from the calibration phantom.

The empirical parameters in this algorithm are limited to the following four:

- 1- R_0 initial half width in pixels of the vessel lumen at the starting point, automatically determined;
- 2- K_d proportionality constant for look-ahead distance (d), where $d = K_d R$ in pixels;
- 3- K_w proportionality constant for search window (w), where $w = K_w R$ in pixels;
- 4- K_s ratio based on the expected vessel size used for the determination of the roll-off point at a density level equal to or less than $(\text{Vessel_lumen} + \text{Background})K_s$.

Initially K_d starts at 0.50, if the search is unsuccessful it is automatically incremented by 0.25 for each iteration. K_w is set to 2.00. K_s varies from 0.30 for the smallest vessels to 0.70 for the biggest.

It can be seen with Figure 1 that the density profile varies greatly with the dimension of the tube. In the upper right corner we have the 0.66mm tube, in the center the 0.78mm tube and in the lower right corner the 5.05mm tube. This variation of the signal (the vessel) level to the background is appreciated by the K_s parameter.

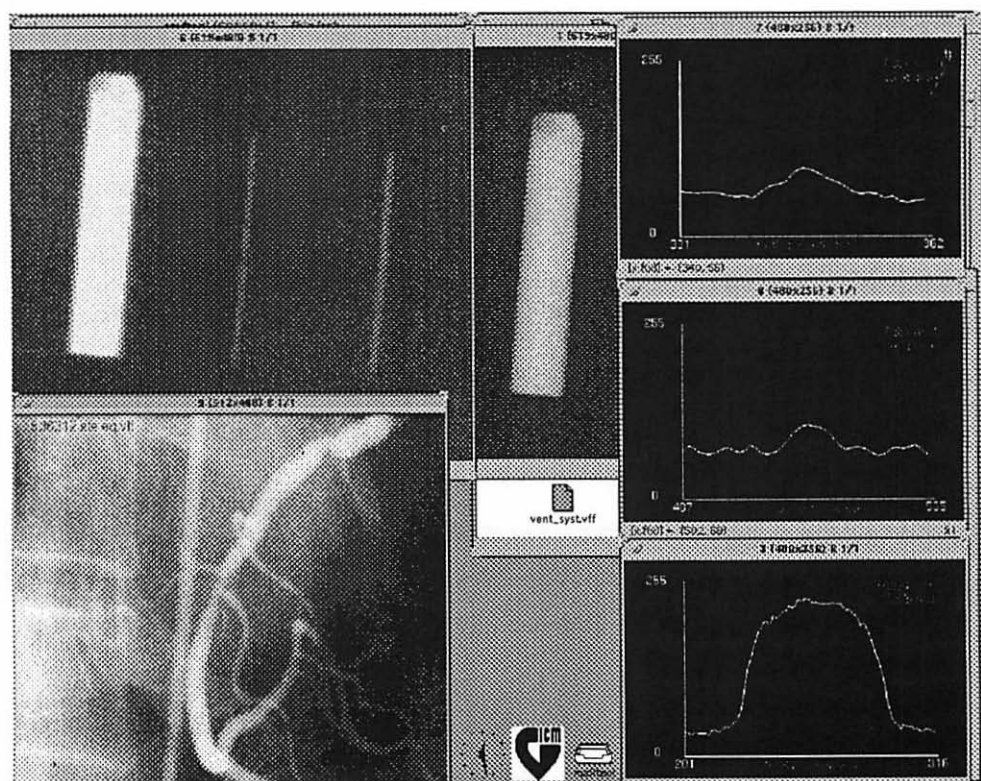


Figure 1 - Density profiles for 0.66mm (upper right), 0.78mm (center right) and 5.05mm tube (lower right).

3.0 Results

The performance of the algorithms was evaluated using a film of an arterial phantom. To simulate clinical conditions, exposures were made with a variety of imaging conditions 70Kv, 90Kv, 5 and 7 inches image intensifier, calibration with a cm grid and with the biggest tube 5.05mm, superposition on plexi base and on a patient as background. The plexiglass phantom contains eleven (11) precision drilled lumens, 5.05, 4.03, 3.56, 3.04, 2.52, 1.99, 1.70, 1.32, 1.01, 0.78 and 0.66mm.

Each was measured over a length of approximately 2 cm. For each vessel, the mean diameter and standard deviation were measured, and these values were compared to the true sizes of the phantom tubes. The overall quality of the contour detection applied to

the vessel phantom is described by the overall mean signed difference (accuracy) between the measured and true values, and by the pooled standard deviation (precision) of the individual measurements. A positive accuracy being associated with an overestimation of the vessel size.

The measurements showed accuracy of $+0.007$ mm and precision of 0.06 mm. These figures can be compared with two commercially available algorithms, Phillips Digital Cardiac Imaging System (DCI) and the Medis (CMS), giving respectively for accuracy (precision), -0.03 mm (0.10 mm) and -0.08 mm (0.09 mm), nevertheless one has to be cautious with the interpretation of those figures since we used signed average.

Figure 2 presents the average difference (measured - true) for the CMS and ICM combining all the imaging conditions.

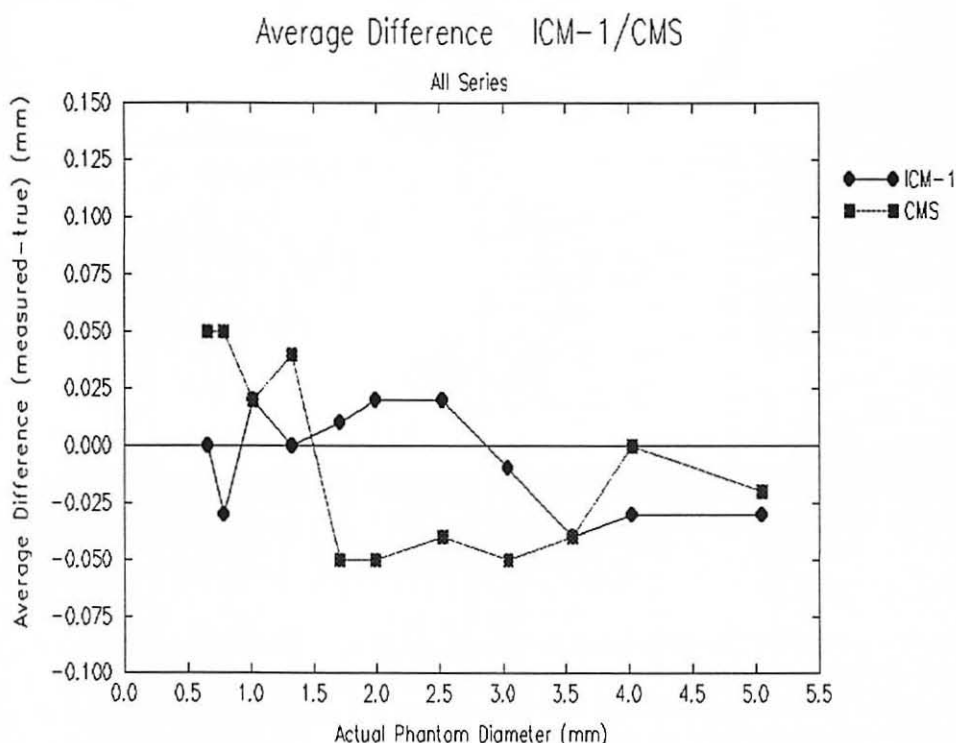


Figure 2 - Average Difference ICM/CMS for all the imaging conditions, 70Kv, 90Kv, 5 and 7 inches image intensifier, calibration with a cm grid and with the biggest tube 5.05mm, superposition on plexi base and on a patient as background.

4.0 Technical specifications

The implementation is opened using X11 window system on any Sun workstations, it

can be interfaced easily with new developments and with data bases.

Figure 3 gives an idea of the available displays. At the center lower part, one can see the diameter function.

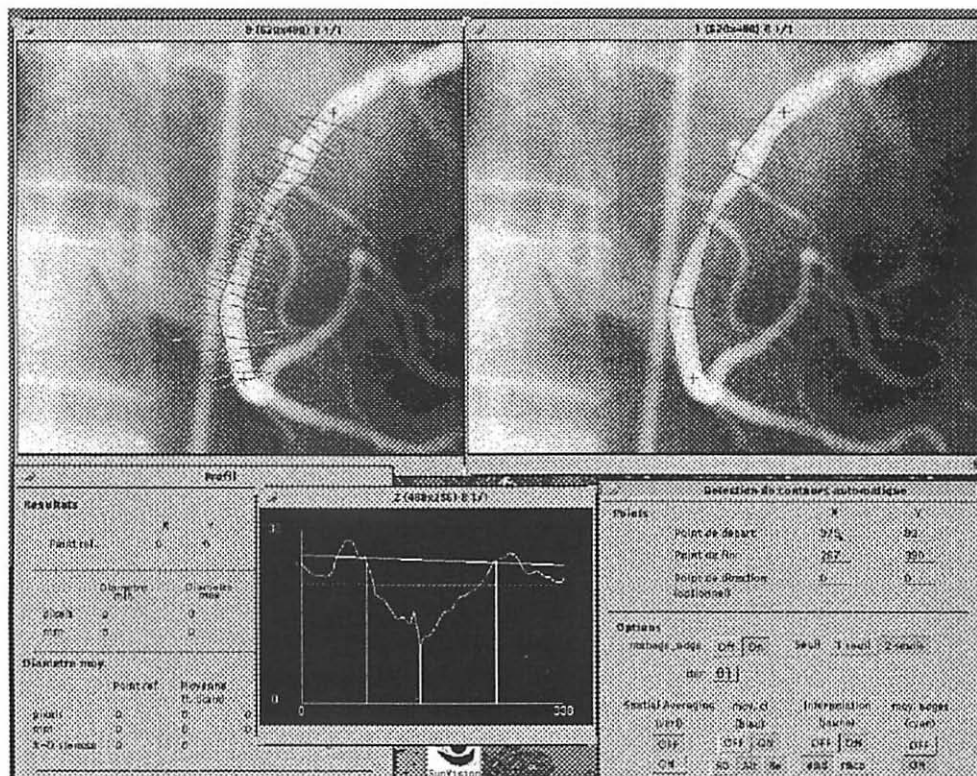


Figure 3 - The system exhibits the possibility of many user manageable windows.

5.0 Conclusion

One of the main feature of this algorithm is its ability to detect small vessels (< 1.5 mm) without the well known overestimation encountered with the algorithms using weighting of the 1st and 2nd derivative of the density profile. In conclusion a new system has been developed for automated identification of vessel contours in coronary arteriograms. By a combined mathematical and heuristical approach the spatial continuity properties of the vessel's position, orientation, and width were incorporated in an adaptive tracking algorithm. The tracking process is fast and robust. The algorithms accurately measured the vessel lumen width over a broad range of image quality and stenosis severity. The authors thank Dr Ying Sun, University of Rhode Island.

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Parametric Myocardial Blood Flow Imaging Using Parallel Virtual Machine (PVM) Software and Compartmental Model Analysis of Dynamic PET Images

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The ability to evaluate myocardial blood flow (MBF) noninvasively has lead to the routine use of positron emission tomography (PET) in the practice of cardiology. PET provides information both unique and complimentary to other diagnostic modalities including echocardiography and single photon emission computed tomography. The clinical utility of PET MBF imaging depends on its ability to answer the specific clinical question: Does the patient have evidence of myocardial ischemia at rest or under stress? Methods to answer this question using PET include visual analysis of tracer activity distribution within the myocardium, semiquantitative polar map display of tracer distribution, and quantitative analysis of myocardial blood flow. This paper will describe a method to quantitate MBF using compartmental model analysis of PET scan data and show our results of applying this model on a parallel virtual machine to create MBF parametric images.

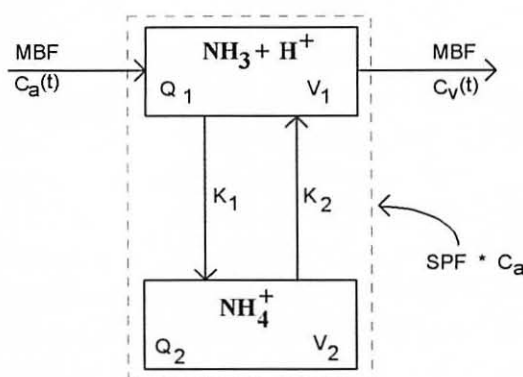
Early work by Hunter¹ showed that intravenous injection of [¹³N]-ammonia (¹³NH₃) yielded an activity distribution within the myocardium which was proportional to myocardial perfusion. ¹³NH₃ is a cyclotron produced agent which decays by positron emission and can be detected by a PET scanner. Today, diagnosis of coronary artery disease using cardiac PET usually is done by the nuclear medicine specialist using simple visual analysis of ¹³NH₃ uptake in the myocardium. It is of interest to quantify cardiac perfusion in order to avoid errors in visual interpretation in those cases with little activity contrast between heart segments and in complicated clinical studies with multiple segmental abnormalities. Quantification may enable the clinician to numerically define risk for ischemic events in selected patients, determine coronary flow reserve, and assess subtle changes in perfusion and metabolism due to cardioactive drugs.

Quantification of MBF using PET requires understanding of the biokinetics of ¹³NH₃. Schelbert demonstrated ¹³NH₃ is nearly completely extracted from the blood pool in the first pass through heart muscle². Following extraction, ¹³NH₃ is metabolized by conversion to glutamine and glutamate by glutamine synthetase.

Within 5 minutes of injection, nearly 50% of the circulating ^{13}N is in the form of urea and amino acids³. A significant portion of the extracted $^{13}\text{NH}_3$ remains trapped in the myocardium, allowing imaging up to 15-20 min following injection. Activity distribution is nonlinearly related to true MBF as measured by microspheres. The non-linearity is a result of decreased tracer extraction at high flow rates as defined by the following equation²:

$$E = 1 - 0.607e^{-1.25/\text{MBF}} \quad (1)$$

where is measured in units of ml/min/g. Using this relationship, Smith⁴ validated a 2-compartment model to estimate MBF as shown below.



<u>Variable</u>	<u>Description</u>	<u>Units</u>
MBF	Blood Flow	ml/min/g
C_a	Isotope Conc. in Artery	counts/sec/ml
C_v	Isotope Conc. in Vein	counts/sec/ml
V_1	Distributed Volume (of state 1)	ml/g
V_2	Distributed Volume (of state 2)	ml/g
Q_1	Isotope Activity (in state 1)	counts/sec/g
Q_2	Isotope Activity (in state 2)	counts/sec/g
K_1	Rate Constant (or flux)	ml/min/g
K_2	Rate Constant (or flux)	ml/min/g
SPF	Spillover Factor	none

With the measured input data providing activity and ammonia concentration in the artery, there are two unknown variables to solve for: SPF and MBF. The spillover factor (SPF), is used to compensate for spatial resolution limitations of the PET scanner. MBF is estimated by the differential equations describing the model

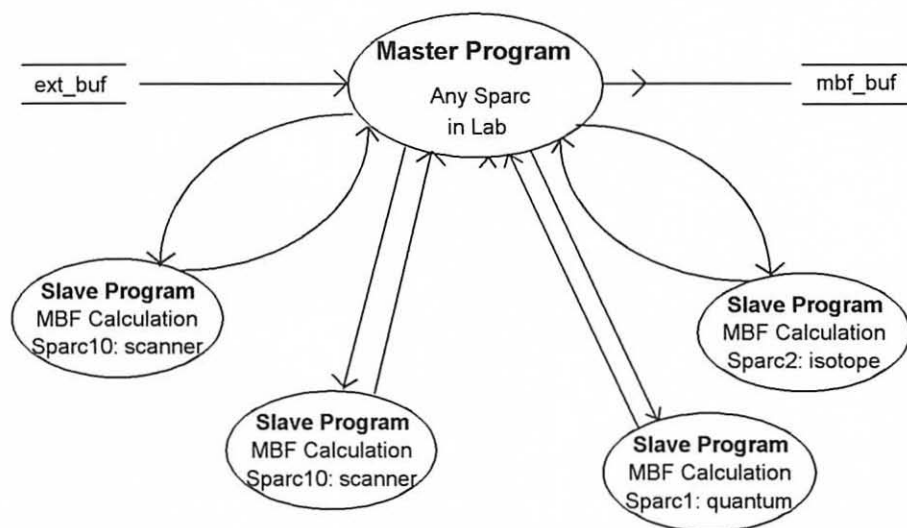
using a non-linear least squares approach (CtrlC, Control Systems Technology, Palo Alto, CA). CtrlC is a computer aided engineering workbench tool which provides matrix analysis, control system design, digital signal processing, and engineering graphics. The CtrlC package implements a solution to the two compartment model by using a maximum likelihood algorithm.

Typical processing times for a single myocardial region of interest calculation requires approximately 9 sec on a SPARC-2 (Sun Microsystems, Milpitas, CA) workstation available in our laboratory. To put the mathematical task of calculating MBF parametric images into perspective, consider running an entire study blindly (processing every pixel on every plane) for one patient with 15 planes. Using a Sparc2 workstation and CtrlC it would take roughly 26 days to do all the processing (16K pixels)!

In preliminary investigation, we determined that the region of interest around the heart comprises about 2000 pixels. Full processing of all planes using the region around the heart would still require over 3 days. Therefore, it is important for parametric imaging to process even fewer points without losing any information needed in the medical analysis. We looked at utilizing two approaches: (1) only process those pixels which have a value above a certain threshold percentage of the maximum value in the image, and (2) averaging four pixels together (blocks of 2×2 , inside the ROI), then processing. We decided to use a simple threshold approach to reduce the number of pixels processed and delayed implementing and testing the four pixel averaging. Our clinical tests supported ignoring pixels that are less than 40% of the maximum value in the image. Even with this reduction, it was apparent that faster processors or multiple parallel processors were necessary to perform the parametric image calculation. Because each pixel to be processed is independent of all others, all MBF pixel values can be calculated simultaneously. This type of application lends itself to a parallel computer where many CPU nodes on a network are all being used to create the MBF image simultaneously. We decided to utilize Parallel Virtual Machine (PVM) software to take advantage of the resources available in our laboratory.

The PVM software very smoothly provides the functionality to use all the workstations on any generic network for this purpose. The functionality of PVM allows the programmer to create a virtual machine consisting of whatever workstations, mini-super and supercomputers that are on the network. With the PVM software, one writes a master program and any number of slave programs. The master program is the first program initiated and controls the starting of all the slave programs that the programmer has specified. The slave programs generally perform the time-consuming calculations while the master program controls the data flow

between master and slave as well as startup and shutdown of the slave programs within the entire virtual machine. In the MBF application there is only one unique slave program which is initiated on each of the nodes.

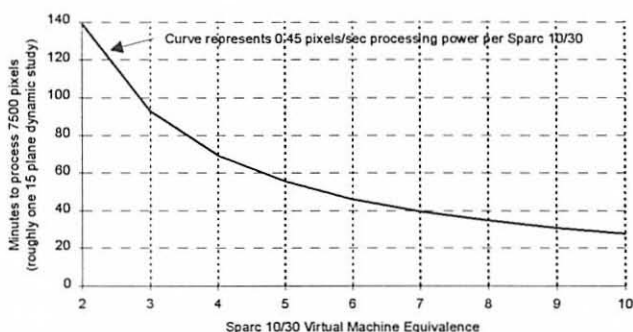


The virtual machine that is set up with PVM can vary from that of a single workstation to one that equals supercomputer power. In the UTMCK Image Processing Lab where this research was developed, we had local area network access (initially Ethernet, then FDDI) to seven different Sun Workstations and regularly used five of them.

Running the MBF calculation virtually pushes the CPU to 100% utilization. Each time the slave program exchanges data with the master program there is a slight drop in the CPU utilization. As expected, the Sparc 2 IPX operating at nearly twice the Sparc 1 rate has twice as many drops. To simplify the load balancing of the machines, the slave programs are not programmed with any assumptions; they just wait for a data set, calculate MBF and SPF, return the results and wait for another data set. The result is that each CPU is operated at full utilization with idle time only occurring at the end of processing a plane where some machines must wait for the last pixel to be processed before data sets from the next plane are sent out. In this project, only those pixels which had an intensity of 60% or greater value of the maximum value in the final dynamic image were processed. This alone reduced the number of pixels to approximately 32% of the total number of pixels in the image.

The equation used to project processing times with additional Sparc Stations then we have in the lab is:

$$\frac{\text{Number of Pixels to Process (500)}}{\text{Pixel Processing Rate, Sparc 10/30 (0.45 / sec)}} \div \text{Virtual Machine Sparc 10/30 Equivalence} = \text{Total Processing Time (sec)}$$



Realistically, it is not possible to process an entire dynamic scan within a few minutes by using only Sun Sparcstations unless four pixel averaging is used. To make a really big impact on processing time one must use a massively parallel machine. Study of the MasPar shows the dominate influence of the massive number of processing elements. The MasPar MP-2 has 4096 processing elements that, in practice, perform about 50 times slower than a Sun Sparc 10/30. Even though much slower, the 4K PEs more than compensate for the lesser CPU performance. For a dynamic scan of 7,500 pixels (roughly one 15 plane dynamic study), a MasPar implementation would produce a turnaround time of roughly 4 minutes. This compares to a turnaround time of 70 minutes on the VM we used in this research project.

Overall, the combination of PVM and the CtrlC engine in a workstation environment is excellent. All the products and code were integrated easily and operate homogeneously. Using several Sun workstations and PVM together to create a virtual machine does provide turnaround times that are conducive for research, but the number of Sparc machines required to achieve turnaround times necessary for clinical practice is slightly out of reach of the current Sparc workstation processing power.

The current method has a useful niche which is to provide an easy mechanism to develop a mathematical research model and to test it. The emphasis is on providing an easy development environment and not on the processing speed of the code or model used.

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Vessel Imaging with CT

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Introduction

CT Angiography (CTA) has demonstrated great potential as a non-invasive screening tool for vascular pathology. The current state of the art in CTA involves imaging the vessels using Maximum Intensity Projection (MIP) technique. The MIP technique depicts the highest intensity regions imaged by CT and projects these regions onto an image plane. The MIP projection displays only a subset of all the information available after image acquisition; it is a 2-D projection and CT data is acquired as a 3-D volume. Although a MIP projection is effective in depicting a general contour of the lumen, some vessel information may be missed. For example, it could miss intravascular pathology, such as a low intensity structure, or a stenosis obscured by a high intensity calcification.

Using a MIP projection as a reference, it is possible to define curved or cross-sectional reformats along a vessel. The curved reformat shows a grey-level cut along the vessel, which could serve as an aid in confirming stenoses suspected with MIP, or as a tool to examine miscellaneous vascular anomalies. Cross-sectional reformats generate a series of cuts of a vessel, tracing along its length. Since all of the acquired grey-level data is used, the information content of this depiction is potentially much more abundant than that of a MIP projection. It is possible to confirm or exclude stenoses, image vascular anomalies, determine the exact location of plaque and calcium, measure the diameter of the lumen and follow any irregularities in the flow with a high degree of reproducibility.

Vessel Depiction with MIP

The MIP algorithm is an effective tool for depicting vascular pathology imaged with CTA (1,2). Although MIP is a popular technique for visualizing CTA data, it has first gained acceptance as the preferred display method for MR Angiography (MRA) (3). In MIP, the 3-D volume is projected onto a plane by casting rays through the volume. Each ray cast projects onto a pixel of the output image, where the value of the pixels

is the maximum intensity value traversed by the ray in the volume. The highest intensity structures of the volume are depicted, while the lower intensity structures are suppressed. In CTA, the contrast agent in the lumen is normally of higher intensity than the surrounding tissues, and is thus depicted by MIP. However, the presence of high intensity structures such as bone or calcium will interfere with the proper visualization of the vascular lumen. The bones must be removed from the original data prior to the application of MIP.

Although MIP provides useful information about vessel pathology, it has some fundamental limitations. Structures of the highest intensity obscure all other tissues, thus the presence of calcifications or metallic stents suppress the display of the underlying vessels. Moreover, low intensity structures, such as plaque, are completely hidden by the superimposed lumen. In a MIP display, the depth information is lost, and it is difficult to infer the relative positions of lumen and pathology. A CINE display of MIP's viewed at varying angles is often necessary to better gauge the depth information.

Vessel Depiction with MPR

One way to visualize vessels while preserving more of the original data is with Multiplanar Reformatting (MPR). This can be done with a curved reformat along the vessel or with a series of oblique reformats perpendicular to the length of the vessel. This kind of depiction is similar to the one used in dental CT applications (4). Since MPR is a 2-D cut of the original volume, grey level information is preserved. Cross-sections of the vessel depicted with MPR show both the lumen and the adjacent structures independent of their intensities or positions. Furthermore, cross-sections can be correlated to the curved reformats along the vessel. The MIP display is an ideal reference for defining both the curved and cross-sectional reformats since the general contour of the vessel present in the entire volume is well displayed.

Results

A renal CTA study was visualized with both the MIP and the MPR techniques. Processing was done on the Siemens SOMATOM Plus CT scanner. The MIP depiction of the renal arteries is shown in Figure 1. The bones were removed from the original data before the application of MIP. The bone editing and the MIP generation were accomplished using the VRT program of the SOMATOM Plus. The entire processing was done in ten minutes. The MPR depiction of the renal artery is shown in Figures 2-5. The Dental program of the Somatom Plus was applied to generate both the curved and the cross sectional reformats of the vessel. The curved reformat (Figure 2) was defined using a cranial MIP view (Figure 3). The cross-sectional reformats were reconstructed along the entire length of the curve (Figure 4). No editing of the original data was necessary. The entire processing was accomplished in five minutes.

Discussion

The cross-sectional reformats (Figure 5) clearly demonstrate the extent of the blood flow through the calcified renal artery. Cross section 30 shows that the right renal artery is not occluded. The curved reformat (Figure 2) also demonstrates the presence of blood flow around the calcification. Such assessment would not have been possible with the MIP depiction alone. Grey-level reformats of the vessels can supplement MIP by providing additional information, as well as, confirming pathology depicted by MIP views. Reformatting is potentially an important tool in better assessing data acquired with CTA.

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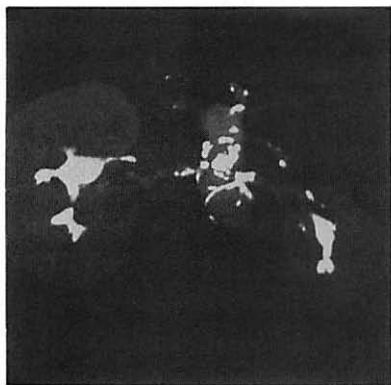


Figure 1. Caudal MIP demonstrates calcified renal artery origins.

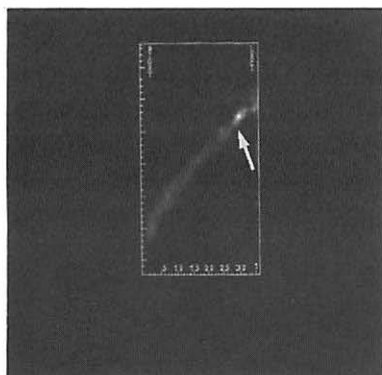


Figure 2. Curved reformation of the vessel demonstrates blood flow around calcification (arrow).

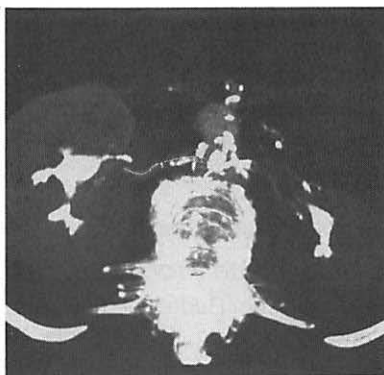


Figure 3. Definition of the curved reformat line.

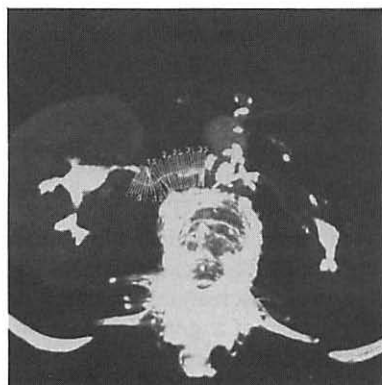


Figure 4. Definition of cross-sectional reformats.

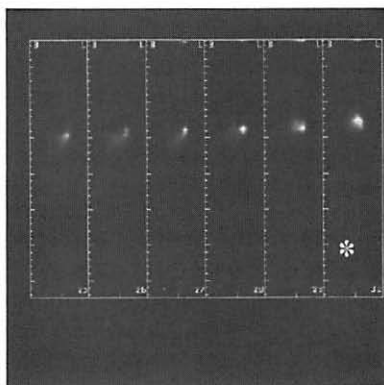


Figure 5. Cross-sectional reformation of the vessel. Contrast is observed adjacent to calcified plaque in view 30 (*).

Motion Correction and Visualisation of Subtraction-Angiographic Data from Spiral CT

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Introduction

On account of the short time required for examination, the technique of spiral-computed tomography provides for possible angiographic contrast medium investigations using CT equipment. The examination time required by spiral CT is something between 20 and 40 seconds and is much below that needed for conventional CT. CT angiography (CTA) is at present still subject of research. Studies have so far been reported on examinations of carotid, pelvic and intracranial arteries as well as on the aorta [2 - 5]. Beside the assessment of vessels additional information about the entire organ is obtainable in the CT data. Thus, the topographic relation between a pathologically altered vessel and its neighbouring structures is clearly visible. This presents a diagnostic advantage compared to other imaging modalities which cannot provide information about soft tissue and bone structures as detailed as CT can achieve.

Conventional diagnosis of CTA images has so far been limited to the assessment of vascular cross-sections, as presented in the slice images. Results are still far from satisfactory when it comes to visual inspection of two-dimensional images for answers to more complicated questions, such as the configuration of a stenosis or the shape of a bifurcation or the course of a given vascular system. Hence, three-dimensional representation of vessels is very helpful.

First of all, it requires the segmentation of the vessels of interest from surrounding structures. Such segmentation of relevant regions is usually achieved by the interactive adjustment of a threshold or by the manual plotting of object contours. However, for at least two reasons neither approach to object definition is suitable for CTA examination: the density of vessels filled with contrast medium is similar to that of many other structures. Second, manual plotting of dozens of object contours for each of the tomographic slices would be an excessively time-consuming, tedious exercise.

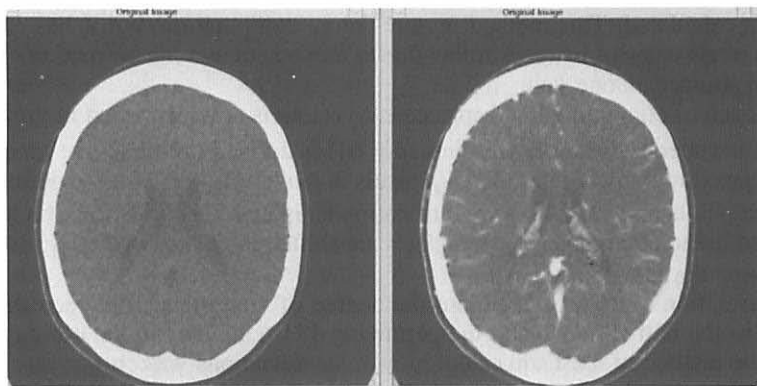
In addition, three-dimensional imaging of vessels by means of the maximum intensity projection (MIP) of unprocessed CTA data is somewhat problematic: the intensity of the contrast medium (CM) is poor compared to that of other structures. In most cases, if MIP is used on unprocessed volume data only the bone is visible on account of its high density. The vessel system with its low intensity is hardly visible at all due to superimposition by other structures. One way to solve this problem is the manual removal of interfering structures like bones by interactive marking. But this manual plotting of regions of interest (ROI) in all CT slices is difficult and tedious and highly time-consuming.

Digital subtraction of native and contrast medium images in corresponding tomograms seems to be a promising approach for the visualisation of CTA data. In an ideal case, this method of image processing will enable exclusive presentation of the contrast medium and is well known from conventional angiography for its excellent results.

1. CTA Imaging

Two separate CT sequences are taken, one native series without contrast medium and one sequence with CM. The contrast medium, usually 100 to 150 ml, is intravenously injected to the patient's arm. CT examination is started 15 to 30 seconds after injection. This delay depends on which organ, resp. which part of the vessel system (arterial or venous) is to be examined. Due to the time required for scanning and preparation of the CM injection, there is a gap of 3 to 5 minutes between the native and the CM sequence. This interrupt is the reason for the patient movements between the two imaging sequences. We used a Somatom Plus S Siemens CT scanner, 512² pixels in resolution. Table feed should be 2-4 mm and slice thickness approx. 2 mm. The CT device parameters have to be set the same for both sequences (table feed, scanning program). The patient is asked neither to move nor to breathe during scanning. In order to keep the time between the two sequences short, image reconstruction from raw data should be done after complete scanning. For post-processing, the CT images of the two sequences are transferred via a network (Ethernet) onto an image processing workstation (Sun-Sparc 10).

The Figs. 1 and 2 show two corresponding tomograms of the head region, (Fig. 1 native, Fig. 2 with contrast medium). The vascular cross-sections with contrast medium in Fig. 2 are not very bright and have less contrast to the surrounding tissue.



Figs. 1 and 2: CTA slices of a brain examination (left: native, right: with CM)

2. Subtraction of CTA images

Digital image subtraction includes subtraction of a native image (without CM) from a contrast medium image of the corresponding plane. This results in a new image that visualises merely the differences between the two original images, which in the case of CTA is the contrast medium. This technique unfortunately is not directly applicable to CTA images, since the calculation of subtraction images on the basis of CT angiography tends to be accompanied by many problems and artefacts. Here are some of them:

- The contrast medium bolus of the intravenous CTA is not as high in intensity as that of arterial angiography.
- CT images usually show a higher number and more contoured objects, as compared to the projection mode of conventional X-ray. Thus, even small displacements of the two images relative to each other may lead to high-intensity disturbances in the subtraction image.

- Numerous, mutually additive and complex motion artefacts may result from patient movements, respiration and movements of individual organs.

The result obtained from direct, uncorrected subtraction of the two tomograms in Figs. 1 and 2 can be seen from Fig. 3. Numerous motion-related artefacts occur at the outer contour and at bone structures. While the vessels filled with CM are somewhat more distinctively visualised than in the non-subtracted image, they are cross-faded by artefact superimposition. To take remedial action on such motion interferences, a new technique for the computation of a more suitable subtraction mask was developed.

3. Correction of motion-related artefacts

All corresponding image pairs of the two CT sequences are successively processed. First, a matrix of displacement vectors is calculated based on the movements of small image regions of the two images. These motion vectors serve as the input for a mathematical transformation to generate a new mask image which incorporates the movements of all local regions. This computed synthetic image has the maximum congruence with the CM image and becomes the new mask in the subsequent subtraction process.

No global approach is taken with our new technique for motion correction. In this approach a large number of local displacement vectors valid for small local image regions is calculated. This method requires more computation, but it has enabled the detection of all types of image warping due to movement and the correction of all kinds of motion artefacts in one step.

The approach of computing the displacement vectors is now described in greater detail. A grid of $n \times n$ equi-distant base points ($n = 64$) is defined on the native image (512^2). Square-shaped regions of interest, T_{len} pixels in length ($T_{len} = 16$), are defined around these base points and are used as identification templates. The position of a template is transferred to the CM image. The templates are shifted in an area of T_{shift} pixels ($T_{shift} = 11$) around the actual base point.

Cross-correlation is used to calculate the degree of congruence between the original template in the native image and the pertaining 121 templates in the contrast medium image. The method of least squares of grey value deviations was chosen as criterion of similarity. Function K to evaluate similarity is written as follows (see equation 1):

$$K_{x_s, y_s} = \sum_x \sum_y \left[(f_{CM}(x_0 + x + x_s, y_0 + y + y_s) - f_{Native}(x_0 + x + x_s, y_0 + y + y_s))^2 \right] \quad (\text{Eq. 1})$$

K_{x_s, y_s}	: cost function at template position x_s, y_s
f_{CM}, f_{Native}	: image function of contrast medium resp. native image
x_0, y_0	: coordinate of base point
x_s, y_s	: shift of template
x, y	: for all points of template

The cost function K is computed for all 121 candidates of a given base point. The template representing the minimum of the cost function is of closest similarity to the reference template in the native image and is chosen as winner from among all candidates. Hence, the position of this particular template relative to its base point gives its displacement vector v . Application of this procedure to the entire image results in a matrix of displacement vectors v_{xy} .

The search for similar regions in the contrast medium image relative to the reference template in the native image will not be carried out unless significant structures are detected in the original template. To increase the reliability of the recognition, only templates with high gradient magnitude are regarded in the search process. Comparison of regions would not make sense if only homogeneous elements are present in the template, e.g. image background. Significant structures are considered to be present if the standard deviation of grey values of the original ROI exceeds a predefined threshold. This limitation will improve both the quality of region recognition and the processing speed.

The displacement vectors are post-processed in the next working step. Mismatches that occur are detected and corrected using the continuity constraint in the correspondences. The orientation of a given vector is compared to the orientations of surrounding vectors to detect "runaways". Should in a 3×3 neighbourhood the orientation and magnitude of a vector stray away from surrounding vectors, that particular vector will be replaced by a weighted mean of its neighbours. Global smoothing of vectors for the entire image is not required and would even be detrimental to the subtraction result.

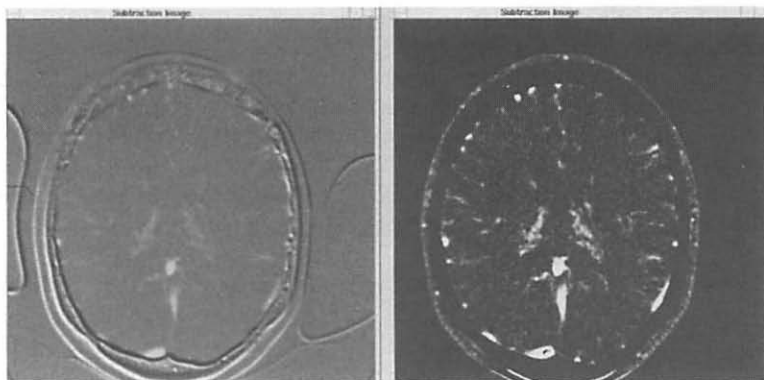
The matrix of vectors thus calculated is used as a framework for computation of additional displacement vectors. An individual vector is determined for each pixel of the image matrix (512×512), proceeding from the 64×64 grid points. These additional vectors are computed with reference to the base point vectors $v_{x,y}$ around the actual point. One actual point, surrounded by four vectors, is the most common case. Bilinear interpolation is used to derive an adequate new vector from the orientations of surrounding vectors. Special cases are applied to the image margin where only one or two neighbouring vectors are present.

The number of base points, template dimensions and magnitude of template displacement are configurable and were optimally adjusted by empirical studies to CTA images. The size of a reference template T_{len} is adapted to the size of significant parts of an object. Template displacements T_{shift} are affected by the expected maximum object movements between the two images. If different types of images have to be handled (CTA, MR, cardiac angiography), these parameters can be readjusted for optimum adaptation of the procedure.

Now, the motion vectors determined are used to generate a new mask image which incorporates the movements of all local regions. The local movement of each pixel is computed and traced back. The pixel of the new mask image is derived from the surrounding grey values located at that particular spot. This computed synthetic mask image has the maximum congruence with the contrast medium image.

Once displacement vectors have been calculated, an appropriate vector is available for each coordinate of the image matrix. These vectors are now used to generate a new subtraction mask. For each pixel of the 512^2 matrix of the native image, the vector related to that coordinate is traced back. A displacement vector can assume real values and, therefore, is not necessarily oriented to one pixel but usually is oriented to a range between more than one. Bilinear interpolation is used again to derive a new grey value from the surrounding pixels. This new grey value is the result which is entered to the new mask image.

This procedure results in a new mask image in which the displacements of all image regions are considered. Finally, the computed synthetic mask is subtracted from the contrast medium image. The outcome of this motion corrected subtraction is depicted in Fig. 4.



Figs. 3 and 4: Subtraction of CT angiograms (l. without, r. with motion correction)

The vessels filled with contrast medium are clearly enhanced after motion correction. Subtraction-related artefacts, as in Fig. 3, have almost completely disappeared.

The method was also implemented for region recognition from two-dimensional to three-dimensional space. In this approach, similar regions were looked for not only on the corresponding slice of the given CTA sequence but also on the adjacent planes above and underneath. However, while much more time was required for computation, the result was not superior to that obtained from the two-dimensional approach.

For CT angiography, displacement of image pairs was mostly found to occur in transversal direction (respiration, patient movement). Therefore, evaluation of two-dimensional images is generally sufficient for consistent results.

4. Visualisation of CTA volume data

On completion of computation of corrected subtraction images for all CT slices, a new series, a subtraction sequence has been created. A separate, special-purpose graphic workstation (Voxel Flinger, ARRI / Reality Imaging, Munich) is used in our clinic for visualisation of three-dimensional medical data. This parallel computer is equipped with a specific hardware architecture to enable fast presentation and manipulation of three-dimensional data. An in-house network (Ethernet / NFS) is provided for direct access from the Voxel Flinger to images computed at the SUN workstation.

The Voxel Flinger provides for real-time presentation of volume data (max. 128 x 512 x 512 voxels), using threshold segmentation, surface modelling, and maximum intensity projection (MIP). MIP includes transmission of projection rays through the data set, with presentation being confined to the maximum grey value along the ray. The Voxel Flinger also provides for fast, interactive manipulation of the three-dimensional data, such as rotations, thresholding, cutplanes and coloured display.

At last, a 3D reconstruction of a CM examination of the brain is presented here. A 3D presentation based on images of direct, uncorrected CTA subtraction results in a worthless representation full of subtraction artefacts. Due to severe interference by motion artefacts at the outer contour and bones, no vessels are visible at all.

The result obtainable from use of the motion correction procedure is shown in Fig. 5. Almost all of the motion-related artefacts have disappeared. The brain vessels can be identified with high contrast. Hence, as opposed to images of uncorrected subtraction, the procedure for motion correction is shown to yield results which lead to a highly

enhanced representation and to clinically relevant information on the vascular morphology.

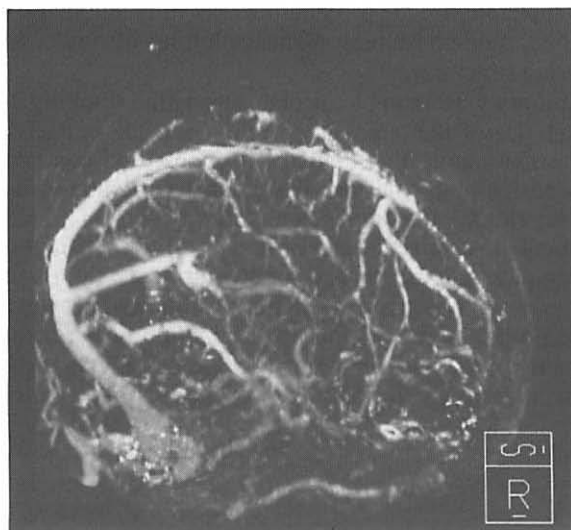


Fig. 5: Brain vessels - presentation after motion corrected subtraction

Summary

Conventional image subtraction of CT angiographic data cannot provide the physician with satisfactory results. Vascular presentation is hampered by severe motion-related artefacts. This shortcoming was the background against which efforts were made to develop a correction method to compensate subtraction artefacts. Small, local image templates in two corresponding CT slices are compared to each other to compute motion vectors which describe region displacements. Knowledge of this displacement pattern is the basis on which to compute a new, adjusted subtraction mask. The high effectiveness of this registration method can be seen from comparison of subtraction results prior to and after use of the correction procedure.

This approach is universally applicable in this area of medical image processing for which generation of subtraction images is required (conventional, cardiac, CT- or MR angiography). Simple minor modification of system parameters is required for optimum adaptation of the motion correction algorithm to any imaging modality under review. The method was successfully applied to CT images of intracranial, pelvic and carotid arteries. The procedure performs completely automatic and no interaction, e.g. demarcation of landmarks, is necessary.

The computed subtraction images are sent to a specialised 3D workstation (Voxel Flinger) where the computed three-dimensional data is visualised. The presentation of the 3D data is done either by a surface model or by using MIP. Three-dimensional visualisation of motion-corrected subtraction images provides for presentation of vessels clearly enhanced over what had been achievable in the past from unprocessed data or uncorrected subtraction.

Conclusions

- 1) The procedure presented in this paper for detection and correction of motion artefacts in CT image subtraction provides for a high presentation quality of the vascular structure. The results of this motion correction are clearly superior to those obtainable from uncorrected subtraction. This procedure works fully automatic and has eliminated the need for tedious, time-consuming manual plotting of object contours or manual removal of interfering structures.
- 2) Images from arbitrary views can be calculated using the resulting 3D subtraction data. This enables the choice of the optimal projection and the best view to the region of interest after the examination. Especially projections, that can not be obtained with conventional modalities (e.g. inferior view), can be calculated instantly and easily modified without interfering superimposition.
- 3) Better assessment of calcified vessels is an additional diagnostic benefit: with conventional techniques, calcific deposits and contrast medium overlay to each other and can hinder the correct assessment of the obstruction. However, the subtraction image enables the proper representation and evaluation of the actual vascular lumen. Given the high quality of vascular representation this procedure of corrected subtraction could become an alternative to conventional angiography, MR angiography and sonography.

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Processing and Manipulation of Pulmonary Magnetic Resonance Images

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I. INTRODUCTION

It is commonly held that magnetic resonance (MR) has a limited role to play in the investigation of pulmonary parenchymal disease.¹ However, with the rapid scanning sequences now available, better lung imaging is possible.² The object of this work was to develop a means of improving the clinical usefulness of pulmonary MRI. This was achieved by various post processing techniques, using CT as a means of correlation. High resolution CT is currently used to diagnose interstitial lung disease, using the appearance of ground glass attenuation as an indicator of activity.³⁻⁶ By demonstrating active and inactive disease MR may have distinct advantages over CT, but it must first be shown that MR is capable of detecting parenchymal lung disease.

High resolution CT scanning produced images of the lungs with high contrast and definition and it was the aim of this study to demonstrate that this MR sequence could be used not only to rival CT but to improve the diagnostic capability of axial scanning. High resolution CT scans are breath held, 2 mm thick at 10 mm spacing. This means that the whole lung field is not imaged. The MR technique however uses contiguous slices. Consequently, the possibility of absolute quantification of disease is only available with MR.

In the normal lung, there is little or no MR signal.^{7,8} This is due to the low number of protons available to provide signal and large number of tissue air interfaces, each of which creates its own magnetic gradient. This tends to degrade the MR signal and is known as susceptibility. Cardiac motion and breathing both produce artefacts and diminish image quality. These problems have in part been overcome by using a rapid gradient echo sequence, using very short TE times, to overcome susceptibility, and breath holding to combat movement.⁹

The sequence described here is a modified TurboFlash technique, performed on a Siemens Impact 1.0 T scanner. Turbo flash uses very short TR times combined with small flip angles to produce 128×128 matrix images in 1 second. A 180° inversion pre-pulse is used to improve signal contrast. The sequence is repeated so that

4 acquisitions can be summed to improve the signal to noise ratio by a factor of $\sqrt{4}$ or 2.

II. IMAGE PROCESSING

The CT and MR images were compared visually to assess that each modality was taken at the same anatomical level. The scans were then transferred via Ethernet to a Sun Sparcstation running ANALYZE™ image manipulation software. The following techniques were then used.

Filtration

The filter that gave the best visual results was the Sigma filter. This is designed to smooth noise, preserve edges and leave thin lines untouched.

Segmentation

In order to allow accurate comparison between CT and MR it was decided to overlay the images. This presented problems of matching and distinguishing two grey scale modalities when superimposed. The MR scan needed to be enlarged, rotated and transposed so that it occupied the same file space and the same number of pixels as the CT slice. In fig 1 the two segmented images are seen before registration. The area within the MR needs to be registered with the lungs of the CT scan.

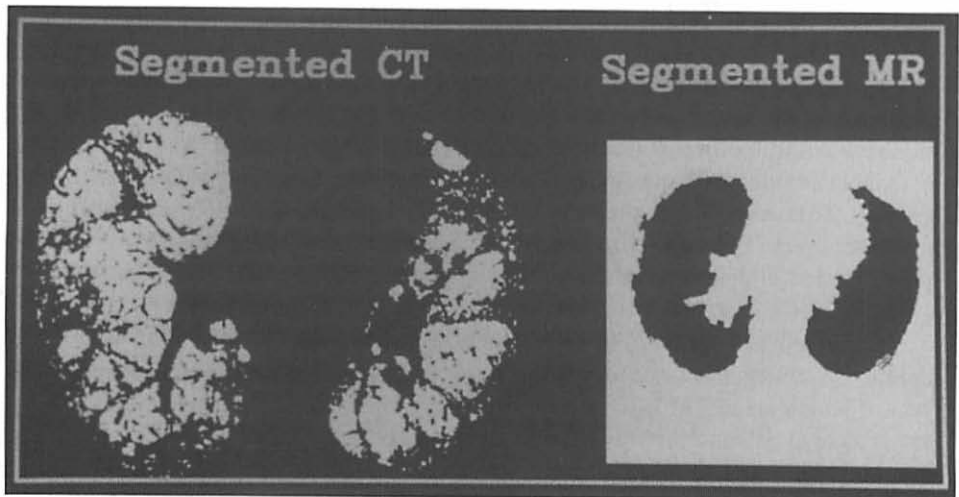


Figure 1

Surface matching

Surface matching calculates geometric transformation parameters between the base and match volumes. Effectively, the two segmented slices are compared and a transformation matrix is generated.

Matrix operations

The original MR image was then multiplied by the generated matrix so that the registered MR image was now the same size and position within the file space as the CT scan. The MR image is a 128×128 matrix whereas the CT is 512×512 . Correct overlay of the images required that each picture matrix is the same, so the registered MR image was converted to 512×512 matrix by pixel expansion.

MR Thresholding

Window thresholding of the pixel values is a standard method of displaying regions of interest within a scan. It was decided to highlight the pixels related to disease as a colour and then overlay onto the CT. All the pixels in the given range are displayed red, whilst the rest of the scan is grey scale as normal. This kind of display has some clinical benefit especially where diffuse disease is present.

Image Algebra

The CT scan has pixel values from -1024 to 3072, and the MR scan values of 0 and 1. The CT values are redefined to run from 0 to 4096 as this is more convenient for the final display. Since the lung tissue is being observed, the appropriate windowing for the CT scan would be -1024 to -200 or 0 to 800 approximately. The colour display of the workstation allows 256 separate colours or grey levels. 6 levels are used to display the screen menu, leaving 250 for the image. The CT values from 0 to 800 were compressed into 249 levels, leaving 1 for the binary MR scan.

Image Display

The display is still grey scale so a colour table was introduced. All pixel values from 0 to 249 are displayed as green and value 250 is displayed as red. Alternatively, the CT data can be displayed as a continuous grey scale and the MR as red. Figs 2 and 3 show the CT and MR scans for a patient with cryptogenic fibrosing alveolitis. In the monochrome image, the disease appears as grey areas around the periphery of the lung fields and correlates well with the ground-glass appearances in the CT scan.

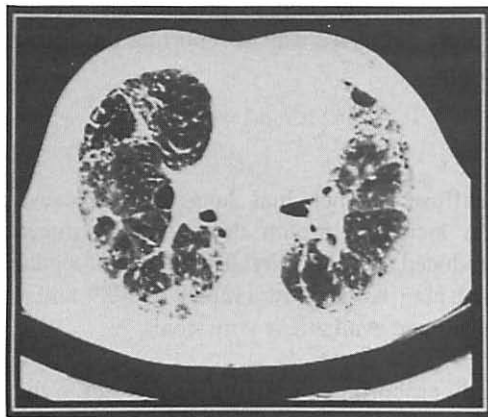


Figure 2 CT

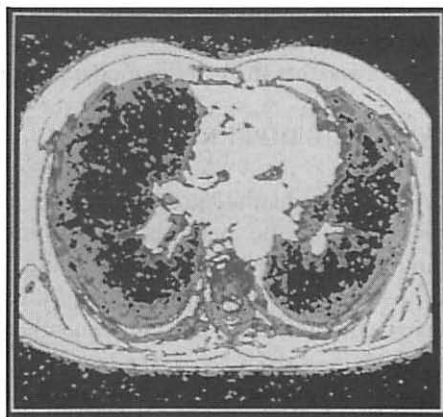


Figure 3 MR

III. TISSUE QUANTIFICATION

Fig 4 shows the MR scan of a patient with cryptogenic fibrosing alveolitis. The diseased area highlighted as "fibrosis" in the right lung has been outlined using a seed pixel and setting the window range to encompass the area of interest.

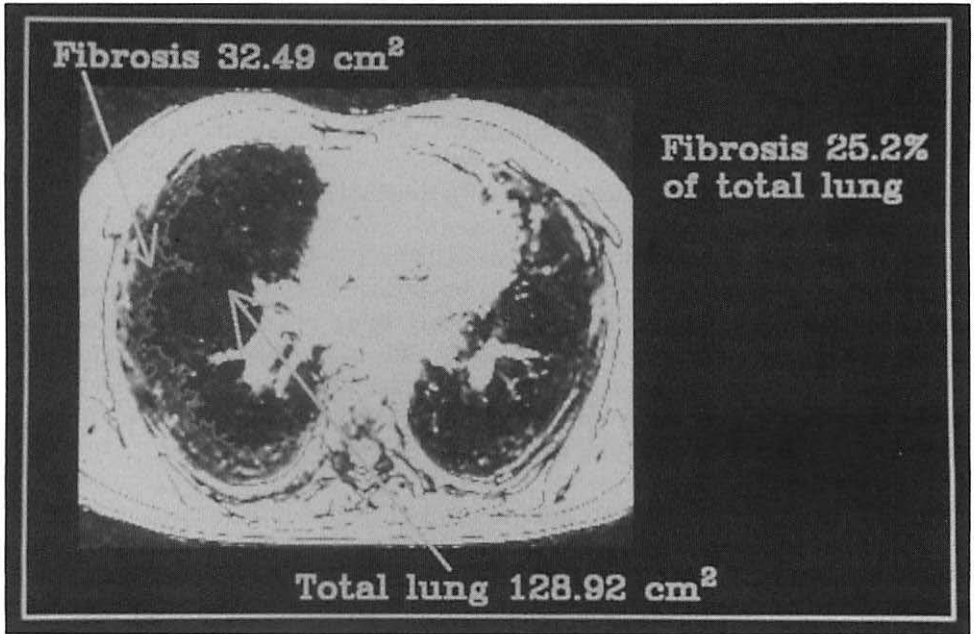


Figure 4

The area of fibrosis has been calculated as 32.49 cm^2 and the total area of the lung in this slice is 128.92 cm^2 . Consequently, the proportion of affected lung is 25.2%. This could be applied to all the slices in the lung to produce an overall proportion of affected lung. This may be a more definitive way of reporting the extent of disease rather than "mild, moderate or severe".

IV. TISSUE DIFFERENTIATION

The pathological processes in diffuse parenchymal lung disease cause thickening of the lung tissue resulting in increased proton density and reduced numbers of tissue air interfaces leading to reduced susceptibility. The values of signal to noise ratio (SNR) in normal and diseased lung is very low (values of 5.89 and 7 have been quoted^{2,10}) and consequently the latitude available is very small.

Signal intensity in MR is not directly proportional to tissue density but to the types of tissue imaged. By colour coding the MR signal intensities, a colour overlay

map can be produced. In order to obtain a reproducible method of relating colour to signal intensity a series of scans were performed on normal volunteers.

We suggest that the diseased state can be simulated in normal volunteers by performing the scan on full or mid expiration. This has the effect of decreasing the lung volume, reducing susceptibility effects and increasing proton density. The SNR was at a maximum of 1.0 on full inspiration and the maximum value reached on full expiration was 10.0. SNR was felt to be a suitable means of normalising the colour distribution and areas of SNR 1 to 4 were coloured red, SNR 4 to 8 were coloured green and areas with SNR > 8 were coloured blue. The use of SNR in MR imaging has been described previously.¹¹

The modified equation we used for SNR is:

$$\text{SNR} = \frac{\text{Signal intensity} - \text{noise}}{\sigma_{\text{noise}} \times 1.53}$$

$$\therefore \text{Signal intensity} = (\sigma_{\text{noise}} \times 1.53 \times \text{SNR}) + \text{noise}$$

So values of signal intensity were calculated with SNR of 1, 4 and 8. The value of noise and σ_{noise} were measured in an area outside the patient volume. The colour display clearly showed the anterior - posterior gradient of signal intensity present with the patient lying supine. Variation with full inspiration, full expiration and suspended mid expiration are clearly demonstrated. The resulting scans will be shown and discussed.

The technique was then used on patients with known pathology (from CT investigation) to demonstrate the feasibility of the method for tissue differentiation and quantification.

V. CONCLUSION

It has been shown that it is possible to enhance the appearance of pulmonary MR images by the use of post processing to generate a colour map. This allows identification of normal and abnormal lung tissue and would appear to be a promising technique for differentiating tissue types. Certainly, the differentiation of active inflammatory disease and inactive fibrosis in interstitial lung disease would increase the clinical utility of pulmonary MR. The active disease may respond to treatment, and repeat scans could then be performed to qualitatively and quantitatively monitor disease progression or treatment efficacy.

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SESSION 6

3-D Imaging

Chair: Ray F. Kilcoyne

3-D Visualization of the Cortical Sulcal Topography

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Abstract—In this paper, we describe tools allowing the 3-D visualization of the deep cortical sulcal topography from a T1-weighted MR image. These tools have been developed in the frame of a project aiming at the automatic detection and recognition of the main cortical sulci. They provide first a powerful assistance to study the interindividual variability of the cortical topography, second an appealing way to locate activations obtained from functional modalities.

1 Introduction

The analysis of cerebral functional data, obtained for instance from positron emission tomography (PET) or magneto-encephalography (MEG), often requires complementary anatomical information obtained from magnetic resonance imaging (MRI). A number of intrasubject intermodality registration methods have been proposed for this purpose [1]. Then, in order to apply various forms of signal averaging to the functional data or to perform comparative studies across subjects, two approaches are possible:

1. Using a standard brain space: the most usual methodologies rely on the proportional system of Talairach [2, 3, 4]. The main limitation of this approach resides in the anatomical variability among subjects. To overcome this limitation, 3-D deformable computerized atlases have been proposed, nonlinear deformations being performed either interactively [5, 6] or automatically [7, 8].
2. Using a set of regions of interest (ROI) specifically defined for each individual anatomy.

Whereas atlas based and ROI based methods perform well for the internal brain structures (thalamus nuclei, caudate nuclei...) because of their low variability [9], they appear much more difficult for the cortical structures (sulci and gyri) because of a higher variability [10, 11].

This paper describes new visualization tools developed in the frame of a project aiming at the automatic detection and recognition of the main cortical

sulci, which would be an important contribution to the design of new methodologies for the human brain mapping researches [12]. This project consists of three main parts:

1. The design of a robust method allowing to extract from a T1-weighted 3-D MR image a high level representation of the cortex topography [13].
2. The constitution of a large database of such cortex representations in which the main sulci are identified [14].
3. The elaboration of a generic structural model of the cortex topography from this database and the design of a method matching this model and any individual cortex representation [15].

The tools described in this paper are dedicated to the 3-D visualization of the cortical sulcal topography. They are used mainly to study the interindividual variability of this topography. Moreover, they provide an appealing way to locate anatomically in 3-D a focus of activation buried deep within a sulcus and hence not visible on the brain surface [16]. This would be particularly interesting for MEG, which is mostly confined to activation from tangential dipoles usually found in the sulci.

2 Extraction of a cortex representation

The representation of the cortical topography extracted from a MR image is an attributed relational graph (ARG). The ARG nodes represent cortical surface folds, i.e. mainly sulcus parts or branches. This ARG is constructed automatically with the following algorithm [13]:

1. Segmentation of the brain using 3-D mathematical morphology.
2. Segmentation of the union U of the cortex and of the cerebrospinal fluid enclosed in the brain hull. Topological and regularization constraints are included in the segmentation process using the homotopically deformable region method proposed in [13], in order to increase the robustness of the further steps.
3. 3-D homotopic skeletonization and pruning of U .
4. Segmentation of the skeleton in simple surfaces (ARG nodes) and junctions between surfaces (first type of ARG relations) [17].
5. Identification of the brain external surface and of the inter-hemispheric fissure in the skeleton (ARG special nodes).
6. Detection of simple surface pairs composing a gyrus using several generalized Voronoï diagrams (second type of ARG relations).
7. Computation of various semantic attributes describing ARG nodes and relations (size, location, orientation...).

3 Identification of the sulci

As soon as the ARG is constructed, the neuroanatomist may label the ARG nodes according to the sulcus nomenclature using a dedicated editor [14]. This editor allows the superimposition of simple surfaces or surface junctions on a 3-D rendering of the brain surface and on three orthogonal slices of the MR image (see Fig. 1). The editor offers a browser which allows the sorting of the ARG nodes according to the various semantic attributes and which gives access to the various neighbours of a node. The identification strategy is hierarchical: first, the larger sulci are identified, then the neuroanatomist looks into the smaller and more variable ones.

4 3-D visualization of the sulci

Identified sulci are then visualized in 3-D using either colored wireframes (see Fig. 2) or surface renderings (see Fig. 1). The sulci can be visualized one by one in order to study the variability of features across subjects (general shape, branches, interruptions). One of our goals is to study the relationship between sulcus interruptions and fiber bundles allowing communication between gyri. The sulci can also be visualized by group in order to study the variable patterns across subjects and the shape of the delimited gyri.

This visualization tools will help to resolve the current uncertainty about the functional significance of individual sulcal patterns. Indeed, they provide an appealing way to study the intersubject variability of the anatomical location of a given focus of activity (the physiological response to a given stimulus).

5 Conclusion

Many of the current limitations facing human brain mapping hinge on the variability of the highly convoluted human cortex. Our project aims to develop robust and reproducible methods to identify various cortical structures. At this moment, the tools described in this paper provide the neuroanatomist with a powerful assistance for the sulcus identification. The next challenge is to automatize as far as possible this cumbersome identification work. The final goal may be to propose an interface allowing the visualization of any individual cortex like the anatomical atlas described in [18].

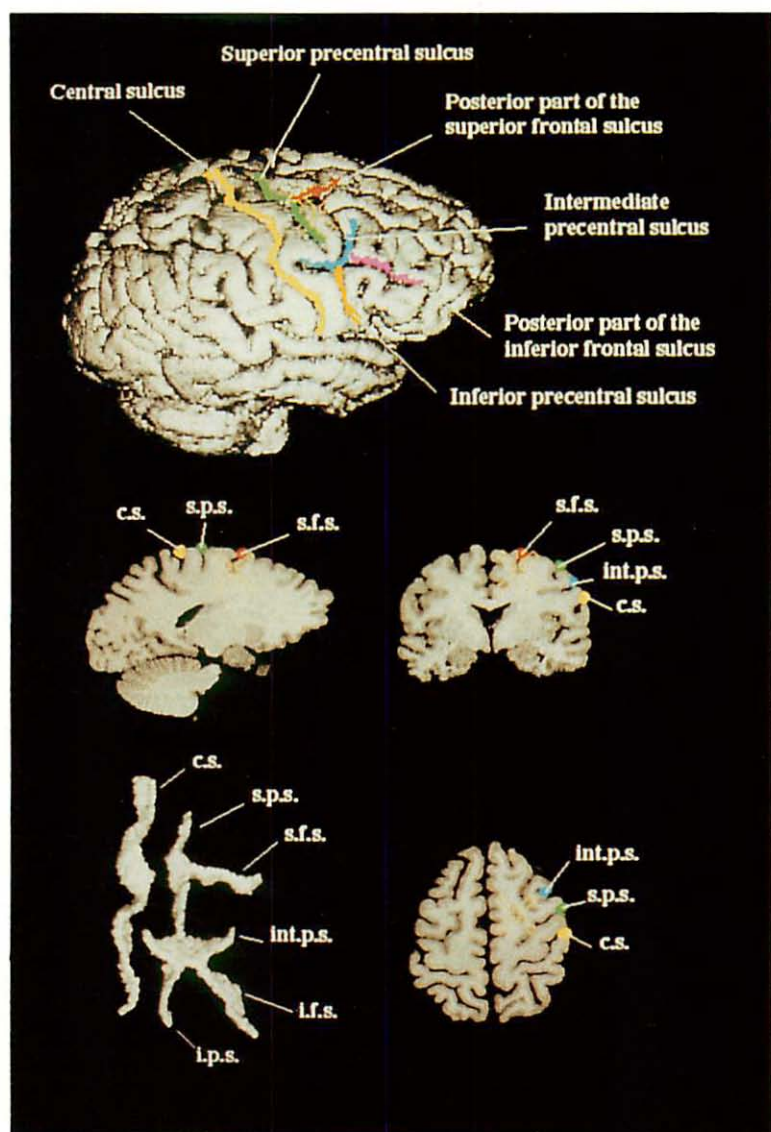


Figure 1: **Surface rendering mode of visualization:** *this figure presents first the visualization panel allowing to label the ARG nodes (in this example, the junctions between several folds and the external surface of the brain are superimposed on a surface rendering of the brain and on three orthogonal MR slices, the four views being interactively conjointly driven by the yellow 3D cursor [14]) and second, a surface rendering of an identified sulcus set.*

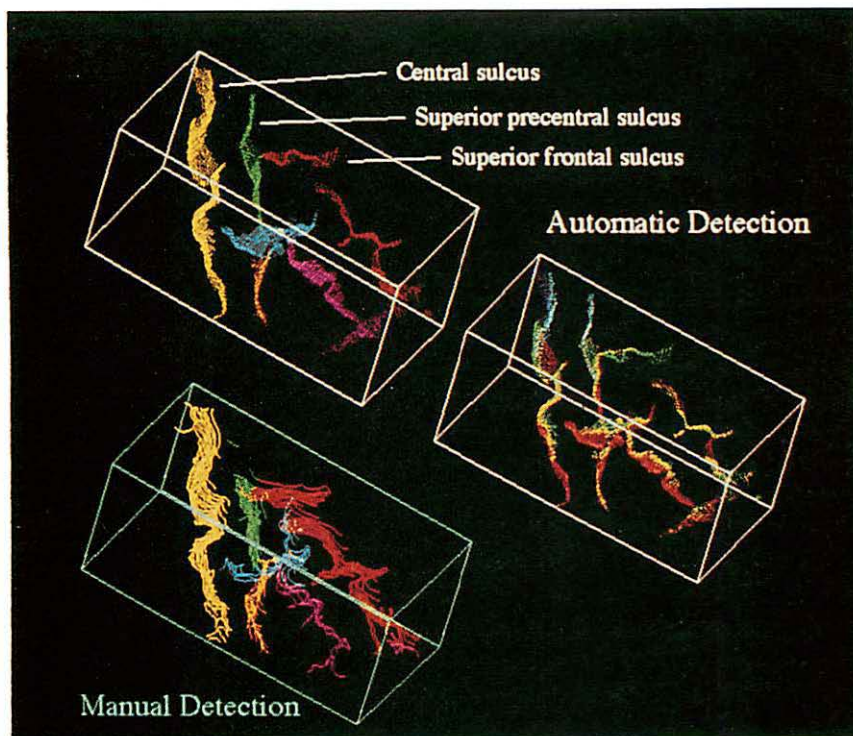


Figure 2: **Wireframe mode of visualization:** the same sulcus set as in Fig. 1 is visualized in 3-D using two types of colored wireframes (one color per sulcus on the left, a color scale indicating the distance to the projection plane on the right). The parallelepipedic box corresponds to the orientation of the MR image (in this case approximatively the orientation of the Talairach frame). The neurologist may interactively change the point of view, select a sulcus to get some information or visualize a slice of the initial MR image. The bottom image corresponds to the manual delineation of the sulci in the slices of the MR image.

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Model-based 3-D Visualisation of the Human Cerebral Vasculature

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I. INTRODUCTION

In brain vascular disorders, accurate 3D reconstruction is essential for diagnosis and treatment planning. True 3D reconstruction of the human cerebrovascular system is hampered by the inherent properties of current imaging systems. X-ray angiography has high vessel resolution but is acquired as 2D projection images. Magnetic resonance images give a 3D volumetric representation of the blood vessel tree of the patient's brain, however they are limited in resolution and contain no temporal information to allow arteries to be distinguished from veins. In current clinical practice, the combination of different types of images is currently accomplished visually by the radiologist and surgeon in order to obtain a qualitative impression of the relative position of the vessels in three dimensions. This may introduce error which can have a profound impact upon both diagnosis and treatment. Our research aims at devising techniques to reconstruct the cerebrovascular tree from the partial information collected from x-ray angiograms and MR angiograms. We look to a higher accuracy result.

In the interests of improving endovascular therapy, our task is the reconstruction of important patient cerebrovascular system elements from the partial information collected from a variety of medical imaging instruments including magnetic resonance angiograms (MRA) slices, and pairs of x-ray angiograms (XRA). Knowledge-based techniques allow us to resolve many of the inherent ambiguities in two-projection x-ray angiography by combining both anatomical and structural vascular information. The association of image processing techniques and a knowledge-based approach has been followed by others^{3,4,5,7,9}. One of the fundamental problems left unsolved is the appropriate type of knowledge and its underlying representation.

Following the results of previous research, we propose a method for model-based 3D reconstruction and visualisation of cerebral vasculature based on symbolic image fusion¹². In our approach to 3D reconstruction, the symbolic, structural model provides guidance to XRA/MRA processing and image fusion, resulting in a patient-

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specific description of the blood vessels. During program development, there is a need to establish an environment for generating a standard data set for determining algorithmic error and to investigate the requirements for different preprocessing algorithms.

This paper discusses our development of a standard data set for the determination of an appropriate knowledge representation and for estimating algorithmic error. The two models described here arise from basic anatomy and from neurovascular radiologists and comprise (1) a structural model represented by frames¹¹ and (2) a Computer Aided Design (CAD) model based on simple geometric elements. We choose to simulate the vasculature with CAD to provide us with absolute control and knowledge of the base geometry. The CAD model allows us to derive pseudo-XRA projection images for different projection planes and we can also generate pseudo-MRA images by voxelisation of the CAD solid model. Test image data sets, both projectional and tomographic, can be computed by introducing image noise, distortion, contrast, and other factors when constructing the derived pseudo-clinical images.

II. GRAPHICAL MODEL

We began the development of the CAD model of the cerebral vasculature by drawing the main arteries and their principal branches, using an 'off-the-shelf' 3D drawing program. Only the centre lines needed to be drawn by hand. We then added the blood vessel thicknesses to the data file output by the drawing program. The vessel diameters were estimated from patient angiograms. This procedure allowed the automatic construction of solid cylinders of corresponding diameters around the centre lines. The resulting model (Figure 1), currently consists of 170 solid tapered cylinders.

We have developed a computer program to simulate x-ray imaging techniques. X-ray angiography is a projection of the imaged vasculature. The two standard views are: Anterior Posterior, where the x-ray source is at the front of the head; and Lateral, where the x-ray source is at one side. In clinical use, images are also often produced as a stereo pair with relatively small angular displacement (commonly 4° to 7°).

Our program can create perspective and parallel projections from different angles of the cylinder model. It also allows specification of a rectangular prism to be used as a clipping volume. The x-ray imaging technique was simulated by projecting a ray through each pixel. The ray is a rectangular prism, one pixel in cross section. The intensity of the pixel is set proportional to the volume of the intersection of the ray with the solid model. The program approximates this volume by computing a number of sample points that falls inside the solid model. To avoid aliasing artifacts, a large number of samples is used. The images can be produced at arbitrary resolutions. Figure 1a shows the lateral view of the Right Internal Carotid Artery and its main branches. Figures 1a and 1b show a stereo pair taken with a 4° angle of separation. After creating the base images, different filtering techniques are used to introduce noise and to show the effect of limited resolution (Figure 2a). For example, a simple

averaging filter can introduce blurring to any desired amount (Figure 2b).

In clinical imaging prior to an endovascular therapy session, images are acquired with various MRA flow protocols resulting in sets of from 30 to 120 axial slices. To create pseudo-MRA images, we take the CAD model of the vasculature and transform it into a set of voxels. Our program can construct these slices by setting the clipping volume to that sampled in an MRA slice. Two slices of the Internal Carotid Artery are shown in Figure 3. These simulate a selective 3D MRA. Variations in resolution (voxel size, aspect ratio, and slice gaps) can easily be introduced. As in the XRA simulations, noise can be added.

The CAD model and associated programs provide an environment in which algorithms that attempt to reconstruct 3D structures from the 2D images can be tested. We have a known structure that can be transformed to simulate the effects of various imaging techniques. Thus, we can perform controlled experiments with the reconstruction algorithms. Some other features of this environment are:

- The model is able to simulate images from typical x-ray angles with exact information of the imaging geometry. This information provides parameters which are required by many reconstruction algorithms.
- Being able to create many projections allows studies which relate the projection angle, the position of the imaged object and the success of the reconstruction technique.
- The model can be enhanced with various additional vascular structures that can be alternately introduced or removed to verify algorithmic robustness. Thus the complexity of the model can grow with time.
- The model can be modified with various pathologies including stenoses, aneurysms, emboli, etc. This allows it to be used in both normal and abnormal situations.

III. STRUCTURAL MODEL

Algorithmic methods for 3D reconstruction have many limitations⁸. They require a number of known corresponding points in the 2D images, and the corresponding points on the imaged object. Knowledge is also required of the distances between the x-ray source, the imaged object and the imaging plane, and the centre of rotation. In practice these parameters are often not known and highly variable. Furthermore, the 3D reconstruction is only an approximation to the original anatomical structure since all imaging techniques lose some 3D information which cannot be fully recovered.

Radiologists deal with this deficiency of information by drawing on their knowledge of anatomy. For example, if the radiologist cannot trace the complete course of a narrow blood vessel, he or she may first locate a known structure and search for the desired structure in its neighbourhood. Many researchers have claimed that if automatic reconstruction methods are to be successful, they must also use model-based strategies, in much the same way as radiologists do^{1,5,6,9}. This model-based strategy is part of our approach.

We construct a structural model that is, in effect, an augmented CAD model which includes additional anatomical, topological, relational and spatial information. We have used a 'frame' representation because it is well suited to 'expectation-driven' programming. By this we mean that frames provide an easy way of identifying properties that our knowledge tells us should be present. If these properties are not evident, then executable procedures, attached to the properties, can be automatically invoked to determine the value of the property. Thus, if we have identified a particular blood vessel and its frame contains information about branches, procedures attached to the branching information can begin a search for those branches in predicted locations. Further enhancement of the knowledge-base will allow the encoding of anatomical variants, so common in human brain vasculature².

IV. USING THE MODELS

To be able to calculate the 3D position of points from stereo images, we must calculate the disparity between corresponding points in the two images. One of the main problems in reconstruction from stereo pairs is the problem of finding corresponding points^{4,10}. In some of our work we use DSA stereo pairs, taken with a 4° separation angle and propose to use the anatomical model to assist in finding correspondence points. To reconstruct the tree structure we use the following information and assumptions: the site of contrast injection (usually the right or left internal carotid artery), the blood vessels represent connected structures and; the blood vessels in DSA are high-contrast regions.

Our reconstruction procedure is as follows. The centre lines of the blood vessels are obtained by applying thresholding and thinning operations on the angiograms. Similar techniques were proposed by Gerig *et al*⁶ and applied to 3D MRA data. The result of these operations is a set of blood vessel segments, many of which will be disconnected because of the inability of the thresholding algorithm to detect faint vessels. These segments may be connected by line-following to form a skeleton-like structure. Unfortunately, line-following algorithms are easily deceived by noise and overlying anatomy and, in many cases, the algorithms require manual intervention^{9,10}.

Using the anatomical model of the vasculature we can match and label the segments belonging to one arterial branch and connect them into a tree structure. The angiogram contains the label of the blood vessel into which the contrast material was introduced. This label indicates which frame represents the root of the tree that is to be constructed. Branching information in the frame indicates where adjoining line segments may be expected or where individual patient anatomic variation deviates from the "ideal" vascular tree. If there are gaps in the image where a branch is expected, a search for the line maybe initiated in the region indicated by the frame in the image. In effect, this is a graph matching procedure which invokes heuristics when there is a loss of information in the image.

We apply the same procedure to each image of a stereo pair. Provided that the blood vessel segments have the same anatomical interpretation in both projections, we can use the labels to identify corresponding points in the stereo images. The calcu-

lation of disparity and the 3D coordinates of each point can now proceed using standard methods¹⁰. A similar procedure can be applied for creating a skeleton structure from MRA volume data. Implementation of this method is still in progress.

V. CONCLUSION

We are developing a prototype system for 3D image reconstruction and visualisation. There are many parameters associated with image capture and these often have a significant effect on the performance of algorithms. This paper argues that there is merit in having a model representation where the effects of these parameters can be studied. Having an anatomical CAD model of the vasculature can be used to generate data sets representing different imaging modalities where the accuracy of the reconstruction algorithms can be measured. Having an anatomical structural model of the vasculature can facilitate the image processing task.

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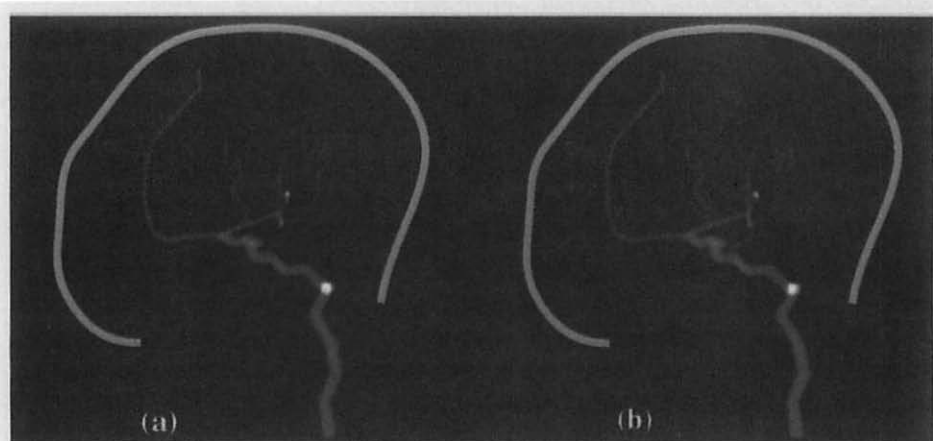


Fig 1. Stereo pair Lateral view

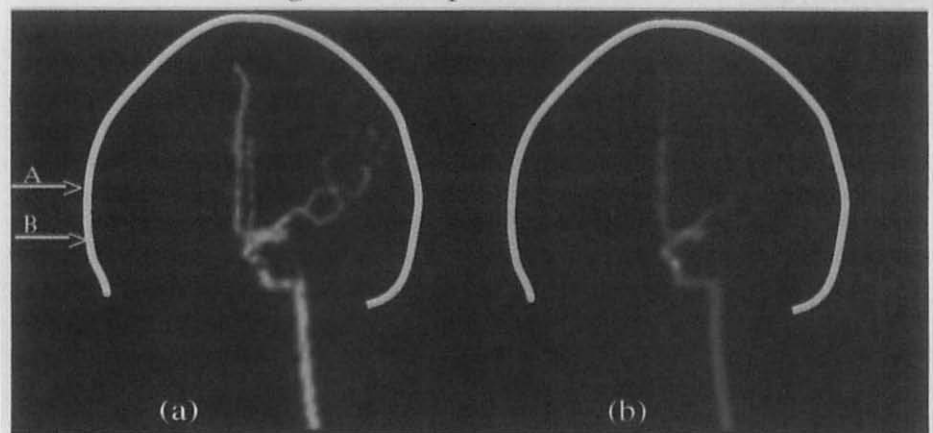


Fig 2. Stereo pair Anterior Posterior view with a) noise b) blur

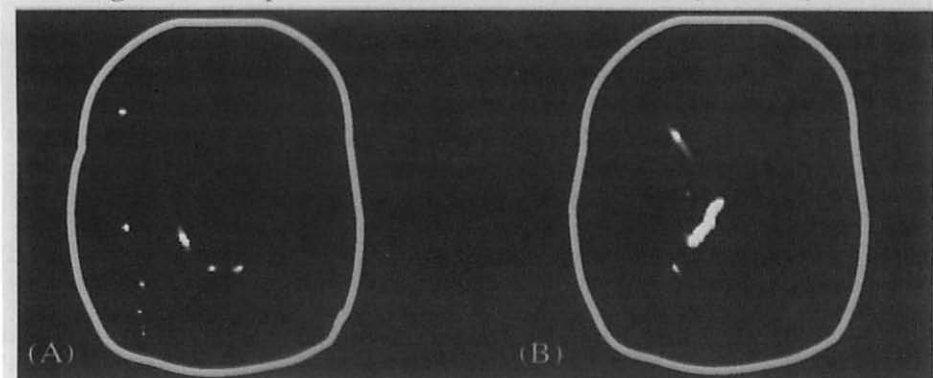


Fig 3. MRA slices at positions shown in figure 2

Three-Dimensional Visualization of the Living Human Brain: On-Line Magnetic Resonance Image Processing

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I. INTRODUCTION

On-line interactive visualization of the human brain's surface and subcortical anatomy is increasingly important for recently developed techniques showing activations of brain perfusion. Functional magnetic resonance imaging (fMRI) is one such novel technique which allows focal blood flow increases in the range of $2 \times 2 \times 2$ mm (8 mm^3 or less in the near future) to be detected in multiple brain planes simultaneously.¹⁻⁴ Techniques for the visualization of such data in realistic three-dimensional reconstructions at the time of such experiments poses a considerable technical challenge. Such techniques are needed to allow rapid feedback on the success of activation paradigms, so that valuable and expensive imaging time is used most efficiently, and experimental hypotheses can be refined during the same imaging session.

This report presents our experience using a networked Unix-based workstation system, designed to facilitate fMRI image acquisition, image transfer and rapid processing to display reconstructed three-dimensional and manipulable brain volumes detailed enough to guide subsequent imaging. At present this system utilizes disparate hardware platforms, custom code and stock applications, but in future will no doubt simplify. This system has made possible an interactivity not previously available during fMRI experimentation, and seems equally applicable to other on-line radiological image processing applications.

II. METHODS

The fMRI experiments reported here required the generation of high-resolution magnetic resonance (MR) images in contiguous thin slices which could be visualized as a realistic three-dimensional rendered volume. This was used as an individualized anatomical reference to determine the specific location of the experimental slice planes (functional images). "Activation maps" are a further functional image derived from a pixel-wise subtraction of the perfusion image of a baseline behavioral condition subtracted from that of an "active" behavioral condition. The anatomical information of the activation images is limited making accurate co-registration of the two types of images essential in determining the specific loci of functional change in an individual activation experiment. The number of variables in such experiments is

vast, and includes subject, experimental paradigm, and imaging technical factors, any of which could invalidate a specific experimental trial's images. Interactive visualization of these images thus offers a significant improvement in fMRI research methods.

Imaging technique

A three-dimensional magnetization prepared, rapid acquisition gradient echo (MPRAGE) sequence is used to acquire the high resolution anatomical image (a 200 mm slab of 128 sagittally oriented partitions, each 256 x 256 acquisition matrix with a 280 mm field of view, effective in-plane pixel resolution of 1.6 x 1.1 mm, TR 10 ms, TE 4 ms, TI 500 ms, TA 9' 17"). Imaging was performed using a whole-body 1.5 Tesla MR with echoplanar capability (Siemens Medical Systems, Erlangen, Germany). fMRI images are acquired using a variety of imaging sequences designed to display differences in blood flow, most commonly based on blood oxygen level dependent (BOLD) T2* contrast²⁻⁴, or more recently echoplanar imaging with signal targeting with alternating radiofrequency (EPSTAR).¹ These sequences usually vary in field of view and pixel dimensions relative to the MPRAGE images necessitating interpolation in co-registration. All images are acquired within a conceptual "magnet space" whose center is at the center of the magnetic field, and uses a tri-axial coordinate system.

All scans have a 6144 byte header which includes details of the incident and in-plane vectors with respect to magnet space, completely specifying the imaged plane's location and offset. The consecutive pixel intensity values (as 16-bit integers) follow this header, file size depending upon the number of pixels in the image. The images are acquired using a Siemens Magnetom running custom Numaris software, and the images are then transferred over the hospital network to a 1 or more gigabyte storage disc. The Numaris software allows simple image manipulations only, necessitating the use of more specialized software. We have chosen AVS (Advanced Visualization Systems, Inc, Waltham, MA) for this purpose. It is resident on a network-accessible Hewlett-Packard Apollo 9000 Series 750 computer, which offers sufficient processing power to manipulate and render the large data sets with acceptable speed. The common scratch storage can be accessed by both systems, and the AVS can be cloned to a Sun SPARC 2 workstation console immediately adjacent to the imaging console. AVS contains general image processing tools, and a modular framework, allowing the easy incorporation of specialized custom C code fragments ("modules") used in a "plug and play" visual user interface environment. We have written custom modules to extract the relevant vector information from the raw image files, in order to register all images relative to magnet space, and hence correctly to each other.

Image processing

Once the remote login procedure has been accomplished, a pre-configured AVS network (the AVS metaphor for a linked group of modules accomplishing a specific task) is activated. This sequentially extracts the pixel information for the MPRAGE images, creates a three-dimensional array of these ("voxels"), and then uses the header information to place this volume correctly in magnet space. This is achieved by using the FovX (field of view in the x direction), FovY (field of view in the y direction), slice thickness, number of slices and center coordinate fields of each

image. Prior to displaying this volume, a custom module implements an automatic segmentation algorithm which effectively removes all of the high signal scalp tissue and many of the brain's thick investing membranes. The algorithm is based on a weighted average and custom edge detection techniques, which seek the low intensity layers deep to the high intensity scalp layers, and then zero all voxels outside this location. It effectively "scalps" the volume providing sufficient detail of the cortical surface for the recognition of anatomical landmarks. A ray tracing algorithm is then used to display a grey scale image of the scalped volume, to allow the planning fMRI slice angles and offsets using the individual unique anatomy. Tools also exist to place a proposed slice plane in the volume, and to reslice this volume arbitrarily to view anatomical relationships. When the desired plane has been selected, the appropriate slice angle and offset is read from the AVS module which created the plane. These parameters match those required by the MR scanner for the fMRI slice planes.

After the fMRI image, eg EPISTAR, is finished, which usually involves a baseline condition image (or images) subtracted from an active condition image, the fMRI image is transferred over the network to the storage site and incorporated into the scalped 3-D volume, using the two normalized orthogonal plane vectors defining the phase and frequency encoding directions. Given these vectors, the magnet space locations of the four corners of the plane are calculated, whose voxel equivalents are then computed with respect to the volume. The location of each pixel on the fMRI image can then be compared with its equivalent voxel location and its 24-bit value substituted for the volume's voxel 24-bit value if the plane intersects the volume at this pixel. Various processing strategies can be used to enhance regions of interest, most commonly involving such steps (each by 1 or more modules) as excluding all pixels with intensities below a calculated noise threshold, computing a fractional change (or other statistic) on a pixel-wise basis, mapping a pseudo-color scale to the intensities, applying a filter, eg nearest neighbor or gaussian, then replacing volume pixels by those of the manipulated fMRI image. The opacity of the volume can be manipulated to make the activation map visible overlaid upon the grey-scale ray traced volume, to allow anatomo-behavioral correlations. On the current system, then image incorporation typically takes between 5 and 10 minutes for each new image or set of images.

Multiple slices can be incorporated into the volume sequentially (or simultaneously), and the further manipulations of the volume performed. For example, it is common to need to re-slice the volume to follow the activation along a cortical landmark, to label or mark an anatomical site (such as a sulcus), or to extract coordinates in other spatial coordinate systems. Relatively simple volume manipulations such as zooming, rotation, translation, arbitrary slicing, or cinematic display are easily implemented. This process can proceed in parallel with the acquisition of the next experiment's fMRI images.

III. CONCLUSIONS

This system currently supports effective on-line visualization of fMRI experimental images and enhances the effectiveness of fMRI imaging sessions. It allows less wasted exploratory fMRI imaging and promotes directed functional experimentation.

There are still difficulties with this technique, most specifically the reliance upon the integrity of the network and several different computer platforms. In addition, the speed of processing these large data sets is only just sufficient to accomplish these on-line analyses, and we await faster more powerful processors eagerly. However, we do conclude that this and future similar systems can provide on-line support for studies of functional human imaging.

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Stereotactic System for Computer-Assisted Radiology and Surgery

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Abstract

We report here the development of a frameless means of stereotactic localization coupled to an advanced graphics work station for interactive computer-assisted interventional radiology and surgery. It provides for real-time, intraoperative visualization, and registration of 3D patient data (CT, MR, PET, etc.). It obviates the need for uncomfortable patient head rings or frames commonly in use for stereotactic craniotomy and neurosurgical biopsy. This technology has been extended for clinical use in spine surgery and CT-table image-guided needle biopsy procedures. Motivations for this work include increased patient acceptance, improved quality of care, and streamlined procedures that reduce costs.

Introduction

Image assisted intervention has the potential to increase the utility of minimally invasive surgery and treatment. Registering previously obtained images to the patient at the time of intervention provides the physician with a patient specific map to guide surgery[1]. Stereotatic neurosurgery takes advantage of previous imaging procedures to guide surgery. This work uses framesless stereotatic methods and real-time computer reconstructed images to allow image guided surgery.

Methods

An ultrasonic 3D digitizer (Science Accessories Corp.) was interfaced to a ViStar medical graphical supercomputer (Picker International). Customized "wands" were build as handheld pointing devices and surgical tools for use with the digitizer. The "wands" were constructed with 2 or more ultrasonic emitters.

The requisite microphone array used to triangulate wand positions was mounted on, or proximal to, the operating table.

Intraoperative registration was performed using three or more small, hollow, spherical fiducials filled with CT/MR visible solution. The ultrasonic wand was used to locate the fiducial positions, providing anatomical coordinates to register the patient's anatomy with the 3D scans. In cases where external fiducials were problematic, as in spinal surgery, bony landmarks served as anatomic reference points. Following registration, multiplanar reformatting software on the work station then locates axial, sagittal, and coronal planes corresponding to the wand tip. Oblique planes normal to (WandView) and inclusive of the wand pointing axis (TrackView) are also presented to assist the clinician. Real-time 3D surface rendering of the patient's CT or MR data provides useful orientation information.

CT guided biopsy was done with the patient on the CT table. A scan of the lesion and area around the lesion was obtained. The scan is then transferred to the ViStar computer. The images are registered to the patient on the CT table using 4 fiducials. This method relies on the relative positions of the fiducials, lesion, and skin not changing or not changing significantly over the course of the procedure.

Results

The reproducibility of a point in space using 4 trials is ± 0.6 mm[2]. The mean linear error localizing 66 points in 22 patients was 3.1 mm sd 1.5mm[2]. In phantom studies done on a CT table placement of a needle tip greater than 7 cm from the surface showed the needle tip to be within 9 mm of the expected location.

To date, the frameless stereotaxy system described here has been used to perform over 190 procedures consisting of neurosurgical biopsy, craniotomy, spinal instrumentation, and CT-table needle biopsy. In a group of patients with gliomas there was a neurological morbidity of 4% as compared to conventional craniotomy in a separate group of controls with a neurological morbidity of 12% [3]. Four CT guided procedures where oblique orientation of the needle was necessary were also done without complication and correct needle placement. Placement of pedicle screws has also been done using bony fiducials.

Conclusion

Compared to traditional framed stereotaxy using rings attached to patient heads, this system has significantly shortened operating room times and overall

procedure cost. It offers interactive visualization of 3D CT/MRI for surgical treatment. System use will be extended to other procedures such as VIP shunt placement, endoscopy, placement of electrodes for epilepsy monitoring, and other interventional radiologic procedures.

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MR-based Spherical Maps of the Human Brain

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SUMMARY

The contribution presents a possible solution for depicting the complete brain surface in one view. The system uses 3D tomographic data. Ray tracing is used to get the map of the brain surface on the sphere surrounding the 3D data volume. Cartographic azimuthal equidistant projection is then applied to map the sphere on the plane. Possible applications include EEG mapping, surgery planning, etc.

I. INTRODUCTION

Research in *brain topography* requires unambiguous and visually clear representations of the morphological structures. 3D reconstruction based on MRI data is a suitable visualization method for such tasks. For example, EEG parameters in mental activities research can be mapped onto a 3D rendered view of the human brain with morphological data obtained from a 3D MRI study [1]. Such mappings are very graphic and allow the use of a large variety of tools for representing the measured data (color, shading, textures etc.) without losing the morphological context. However, this visualization method has a significant drawback: More than one 3D view is required for a complete description of the whole brain surface (usually, the left and right lateral views and a top view are used).

In our work, we have used a simple method for producing *maps of the human brain* that depicts the complete brain surface in one view using ray-tracing and cartographic projection. We call this method *spherical mapping*, because the primary projection maps the brain surface onto a surrounding sphere.

The current contribution gives a brief explanation of the geometry of the spherical mapping, describes the practical procedure of handling the data and brings illustrative examples.

II. GEOMETRY OF THE SPHERICAL PROJECTION

Standard volume renderers produce planar projections of the objects. In this case, rays are cast in parallel (axonometric views) or in bundles (perspective views). Such images correspond to the common visual perception and are therefore 'realistic'. However, the ray-tracing-based volume rendering can be used not only for generating realistic scenes. For example, if the projecting rays are normal to a non-planar surface in all its points, we get a map of the depicted objects on this surface (this is similar to the well-known *texture mapping*).

We have proposed to use a *sphere* surrounding the 3D volume block as the reference surface for mapping brain structures (Fig. 1). The rays are cast normally to the spherical surface towards its centre and the characteristic values of the ray-object intersections (according to the shading method chosen) are mapped onto this sphere (called *projection sphere*).

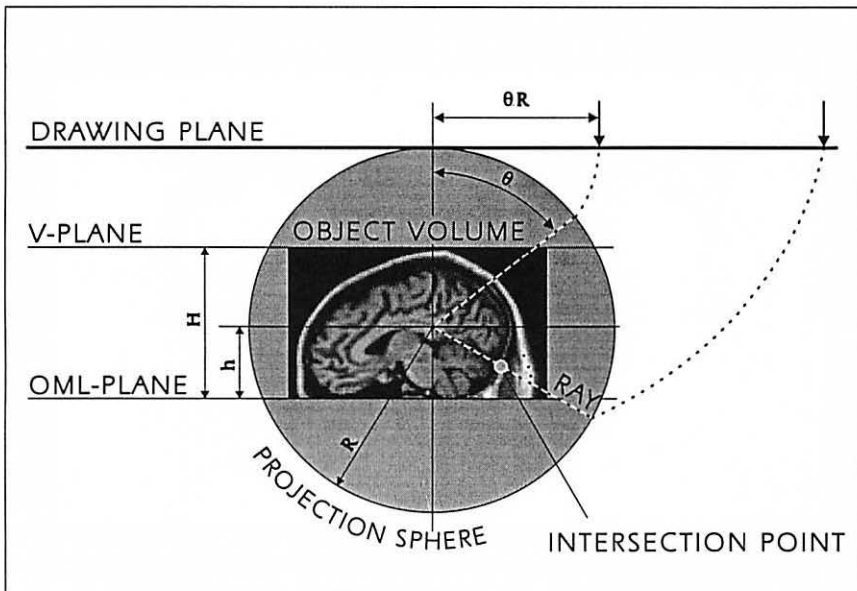


Fig. 1: Geometry of the spherical mapping.

The most critical factor of the mapping is the choice of the centre of the projection sphere relatively to the depicted object. In order to achieve standardization, anatomic landmarks have to be used for positioning the mapping coordinate system. We propose the use of the *orbito-meatal (OML) plane* as the base, since the whole brain (including cerebellum) lies over this plane in most cases. The point on the skin surface of the supra-OML part of the head with the maximum distance from the OML-plane has been defined as *vertex*. The centre

of the projection sphere lies on the normal to the OML-plane passing through this vertex.

The height h of the centre over the OML-plane (relatively to the vertex-to-OML-plane distance H) has to be optimized with respect to the quality of mapping. Intuitively, a good mapping quality can be achieved when the projection rays are normal to a smooth, approximating hull of the object. In the case of the brain, for example, using this hull we get high depth contrast between sulci and gyri. A typical brain form (i.e. its convex hull) is non-spherical with a considerable difference in curvature measured in the sagittal and coronal planes (see Fig. 2). Thus, the optimum height h has to be found as a trade-off between the sphere that would optimally map the sagittal region (i.e. the region of the brain surface close to the sagittal plane) and the sphere mapping optimally the region near the plane perpendicular to the OML-plane and passing through the vertex. In our experiments with various data sets, we have found the value $h \approx 0.1H$ to be optimal. However, using this value, the maps of the temporal and occipital lobes exhibit lack of details of the cortical structure (see Fig. 4).

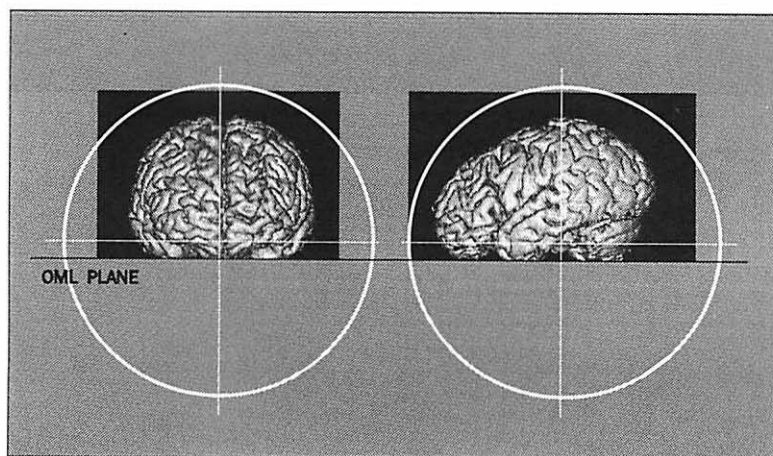


Fig. 2: Setting up the optimum centre position of the projection sphere in the two mutually perpendicular planes. (This figure depicts the actual geometrical configuration used for rendering Fig. 4 and 5.)

The problem of transforming a coordinate system defined on a non-planar surface to a planar coordinate system is solved in *cartography* ([2]). Obviously, the problem is non-trivial in the case of *undevelopable surface* (e.g. sphere), if certain geometrical conditions are to be met. In standard cartography, such conditions can include conservation of distances, angles, areas, or some combination with optimization of some composed distortion function. These conditions make sense when the depicted objects lie closely to the spherical surface. In our case however, the sphere is only an intermediate geometrical abstraction used to

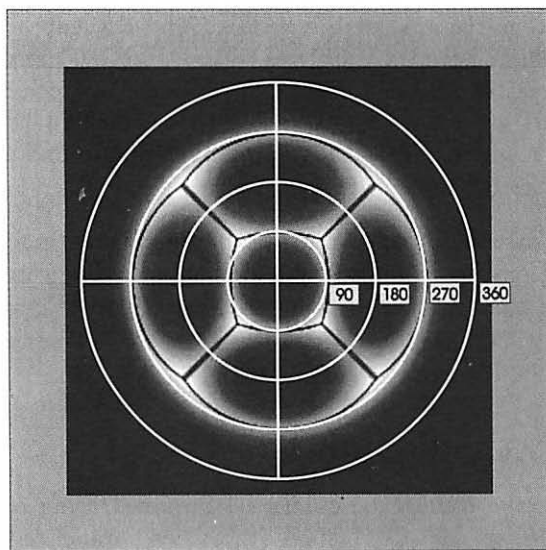


Fig. 3: Full-scale spherical map of the cube (the cube centre and the projection sphere center coincide). The numbers stand for colatitude in degrees.

determine ray directions. Therefore, the simplest transform is the best choice. If the drawing plane is tangential to the projection sphere (the common point is called *pole*), the natural solution is to define a polar coordinate system (r, ω) in the drawing plane with the pole as the origin and

$$\begin{aligned} r &= R\theta \\ \omega &= \phi \end{aligned} \quad (1)$$

Here, (θ, ϕ) is the spherical coordinate system on the projection sphere (θ stands for *colatitude* – the angular distance from the pole; ϕ stands for *longitude*), and R is the radius of the projection sphere. The parameter R has only the meaning of the magnification factor. This mapping mode is called *azimuthal equidistant projection (AEP)* in cartography, because the radial distance r is equal to the geodesical distance from the pole to a given point (θ, ϕ) on the sphere. Obviously, this transform is a one-to-one mapping between the points on the sphere and the inner of a circle with the exception of the opposite pole.

In order to demonstrate the characteristic geometrical distortions introduced by these mappings, Figure 3 shows a cube projected by AEP. In this case, the centres of the projection sphere and of the cube phantom coincide. Gradient shading was used to render the surface, therefore the darkest regions correspond to the points on the cube that are hit by the rays perpendicular to the surface.

A full-scale spherical map of the brain is shown in Fig. 4. The polar

coordinate system is centered in the vertex. The concentric circles represent the parallels at 90, 180, and 270 degrees, respectively. Clearly, the area above approx. 270 degrees is unusable due to the extreme distortion. Note that the large black regions are caused by 'holes' in the segmented brain data set (no surface defined). A practically usable map provided with anatomic descriptions of the major regions is shown in Fig. 5.

In standard mapping mode, the luminance of the pixels is used for shape coding (e.g. using common gradient shading). The chromaticity coordinates of the pixels can be freely utilized to represent measured data (EEG, as in our application) or any other relevant quantity.

III. PRACTICAL PROCEDURE

At first, the tomographic data set obtained using a 3D scanning sequence is resampled to para-OML slices (the slices parallel to the OML plane). The data is then segmented using an interactive tool based on thresholding and repeated applications of morphologic and connected component labeling operations ([3]). The position of the vertex is found as the centre of gravity of the highest non-empty para-OML head slice. The mapping software (*brm* – BBrain Mapper) is implemented as command-line-driven program allowing setting of geometric parameters (positioning of the projection sphere, magnification), various shading modes, etc.

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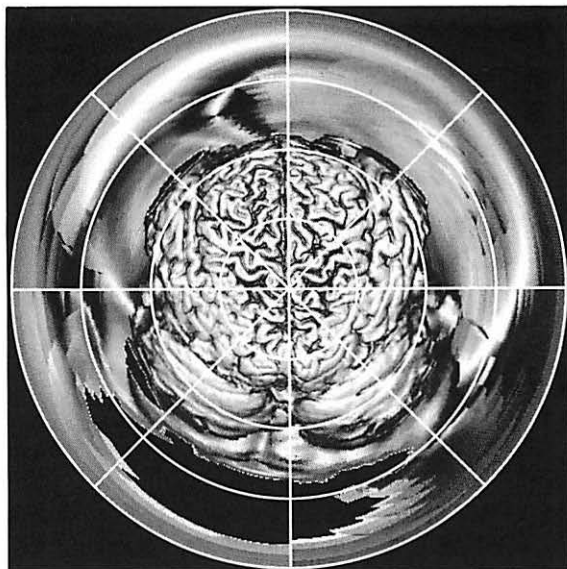


Fig. 4: Full-scale spherical map of the brain.

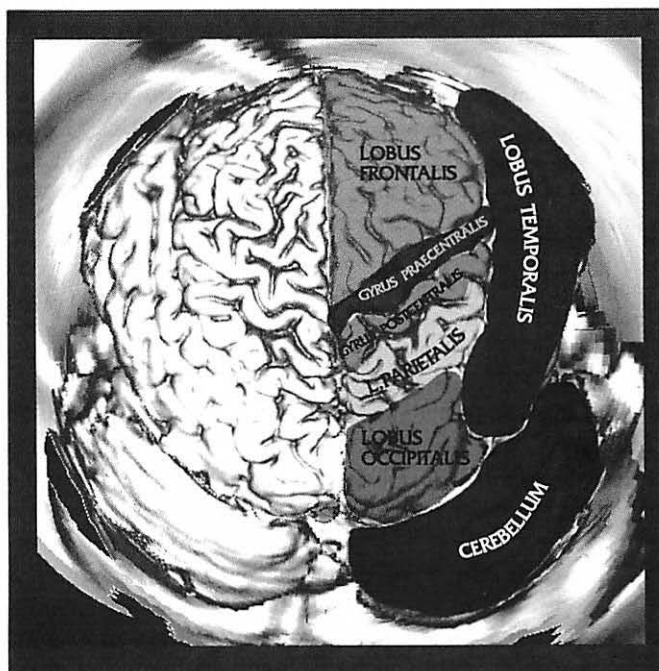


Fig. 5: Relevant detail of the map with anatomic descriptions.

Detection of Discrete White Matter Lesions After Irreversible JPEG Compression of MR Images

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I. INTRODUCTION

Much attention has been directed recently to the compression of images for the purposes of archival and transmission. The recent effort by the American College of Radiologists and the National Electrical Manufacturers Association (ACR/NEMA) to define a workable standard for the interaction of medical imaging equipment has highlighted the need for effective evaluation of compression techniques included in such standards. The Joint Photographic Experts Group (JPEG) has defined a standard that includes an irreversible compression technique using the Discrete Cosine Transform (DCT), which has already been widely applied outside the medical imaging community.

Irreversible compression techniques potentially allow for more effective use of limited storage and transmission bandwidth than the less effective reversible compression methods. Before such methods can be adopted for medical applications both the fidelity of the reconstructed images and the effect of any information loss on diagnostic accuracy must be evaluated.

Magnetic resonance (MR) images are somewhat different from other forms of radiologic images in their spatial and contrast resolution, and noise characteristics. Though individual images are small, they are acquired in ever increase volumes as faster acquisition techniques proliferate, hence the need for effective compression techniques is increasing. The different nature of MR images requires that evaluations of irreversible compression be specifically directed, rather than drawing conclusions about effectiveness and accuracy from studies of other modalities.

In this study, brain MR images of differing contrast are compressed using one of the JPEG algorithms at varying degrees of compression, and evaluated by a team of neuro-radiologists for a specific diagnostic task involving the detection and enumeration of discrete white matter lesions. The purpose is to determine whether the JPEG algorithm is suitable for this application, and

what degree of compression can be achieved before diagnostic accuracy suffers. The hypothesis is that a greater degree of compression can be achieved than with reversible compression techniques while still preserving sufficient information to maintain diagnostic accuracy. These results will be used to plan the methodology of a larger, more rigorous study.

II. METHODS

Sixty intermediate weighted (IW) and T2 weighted (T2W) images were selected by one neuro-radiologist from a group of patients undergoing routine MR examination of the brain. Only patients with normal images or images showing evidence of white matter disease were included. Those with space occupying lesions were excluded. Images were acquired on a General Electric Signa 1.5T magnet with 4X level software. Conventional multi-planar spin echo acquisition parameters include a repetition time of 2800 ms, echo times of 30 ms and 80 ms for IW and T2W images respectively, a slice thickness of 4 mm, a matrix size of 256 and a field of view of 200 mm resulting in an in-plane resolution of 0.78 mm per pixel.

Image data was transferred to a Sun SparcStation IPC for processing. The code from the Independent JPEG group (IJG) version 2b was modified to read and write 12 bit images and used to compress each image at five different degrees of compression. The compressed images were then decompressed, converted back into images acceptable to the Signa, and pooled to form a total of 360 images. The order of images in this series was then randomized to prevent observers from correlating the same image at different degrees of compression.

The images were then transferred to a Signa diagnostic console for evaluation. All observations were made at the console. No images were printed. The observers had access to the limited imaging functions on the console, which included adjustment of window level and width and magnification, but no form of filtration.

Three other neuro-radiologists experienced in reading brain MR images then evaluated the entire series independently. Each was asked to determine for each image, the number of discrete white matter lesions in size categories of <2 mm, 2-5 mm, and >5 mm, and the presence or absence of confluent peri-ventricular white matter changes (CPVWMC). Each observer was also asked to make a subjective assessment of image quality on a scale of one to five.

The degree of compression and its effect on image quality, the number of lesions stratified by size, and the presence of peri-ventricular disease, was evaluated using the uncompressed image as a standard. Comparison was

performed using the non-parametric Wilcoxon's matched pairs signed ranks test for lesion detection and the McNemar test for matched pairs of dichotomous values for peri-ventricular changes. Significant differences were regarded as present when the two-tailed probability of a difference was less than 5%. A two-tailed test was chosen as the compression process could conceivably alter the image in a manner that improved lesion detection.

III. RESULTS

No significant difference in number of lesions detected was apparent until compression ratios reached 40:1 ($Z = -6.63, p < .0001$). This was despite a highly significant difference in subjective assessment of image quality observed at compression ratios of 20:1 ($Z = -6.22, p < .0001$). However, even at the highest level of compression, significant differences were observed only for small ($\leq 5\text{mm}$) lesions. No significant differences were observed in the detection of confluent peri-ventricular white matter disease at any level of compression tested. The same results were obtained when IW images and T2W images were considered separately.

IV. DISCUSSION

The cost of archival storage media and transmission bandwidth remains relatively high despite recent advances in technology. The increasing volume of digitally acquired medical image data is driving the search for more effective compression techniques. Reversible techniques have been applied to the compression of MR images, but even with techniques especially chosen to handle such images, compression ratios of at most 3.05:1 have been attained (7). A ratio of 2:1 is more typical (10). The effectiveness of compression is limited by the relatively high level of noise (10) and the high contrast resolution and low spatial resolution (7) compared with other modalities.

A family of irreversible compression algorithms has developed using the principle of transformation into the frequency domain to decorrelate components of an image to facilitate more effective entropy encoding. The Discrete Cosine Transform (DCT) is usually chosen as algorithms are known for fast discrete implementation, it closely approximates more ideal transforms for decorrelation, and has only real components in the frequency domain unlike the Fourier Transform.

Greater compression can be achieved by selectively quantizing frequency components that carry information of less importance to the diagnostic process, such as the higher frequency coefficients that carry edge rather than contrast information. It is the selection of the quantization parameters that primarily dictates the effectiveness of compression and the degree of

information loss. An effective and reversible method of encoding is chosen for the subsequent entropy encoding such as Huffman encoding.

What distinguishes variations on this theme, are whether the image is transformed as an entire image (1,11) or split into smaller blocks, whether adaptive techniques are used on a regional basis to locally optimize the quantization process (6,8), and whether special techniques such as bit allocation are used to handle images containing significant edge and contrast information (2,3,4). The JPEG process chosen (extended sequential DCT-based mode with Huffman coding and 12 bit sample precision)(9) splits an image into 8 by 8 pixel blocks and uses the same quantization algorithm for the entire image, and in some ways represents the worst member of such a family for this application. It is however computationally the simplest, amenable to commercial hardware implementation (most of which are for 8 bit deep data only however) and well understood. A well tested and freely available software implementation that runs on almost any processor was available for this project. The entire family of reversible, irreversible, and hierarchical compression techniques described in the JPEG standard has been incorporated as the basis for compression in the new ACR/NEMA Digital Image Communication in Medicine (DICOM) standard version 3.0, and hence is destined to be the focus of considerable attention.

The application of these irreversible techniques to medical images has received scrutiny before. High resolution (4,096 by 4,096) scanned radiographs of the hand compressed with a full-frame technique were found to retain diagnostic information up to a ratio of 28:1 for the difficult task of detection of subperiosteal resorption (1). Digitized chest radiographs have been compressed with adaptive block based techniques achieving compression ratios of 25:1 (8) and 20:1 (6) before loss of diagnostic accuracy. Application to MR images has been described, but without evaluation of the effect on loss of diagnostic information (3,5).

The diagnostic task chosen in this study to compare the effect of compression is one that entails detection of both small and large lesions in relatively high (T2W images) and low (IW images) contrast conditions. The lesions are common enough that a sufficient number of cases could be acquired, and the task has clinical relevance in that the number of lesions is regarded as being of prognostic significance, particularly in the setting of demyelinating disease. Each lesion represents a discrete signal that is either present or absent, reducing the ambiguity in the observer's mind.

The technique of analysis was chosen to provide a mechanism for determining the probability of a significant difference between images. Many similar studies use the ROC methodology for this purpose. That technique was thought unsuitable for the present task that involves counting lesions,

rather than assessing a degree of confidence in their presence or absence. Though it is fashionable to quote sensitivity and specificity in such situations, without a meaningful gold standard to refer to, these parameters have little meaning outside a single study. Rather than recast the problem into one suitable for ROC analysis, a non-parametric comparison of lesion counts considering matched pairs maximizes use of the available data.

The findings suggest that for the specific task of detecting and counting discrete white matter lesions and detecting the presence of peri-ventricular changes, high degrees of compression can be tolerated. Interestingly, the subjective assessment of image quality reduced significantly at lesser degrees of compression. For this kind of image, it would appear that compression of at least 10:1 can be tolerated before there is a perceptible loss of quality, and 20:1 before there is a loss of diagnostic accuracy. Contrast enhanced difference images between the uncompressed original image and the compressed image appear to contain very little anatomical structure. With a greater degree of compression, more structure is apparent. Though artifacts due to the block-based algorithm used are perceptible with higher degrees of compression, these are neither particularly prominent nor objectionable. No difference was seen when T2W images and IW images were considered separately, presumably reflecting the fact that these lesions have a high contrast with the white matter on both types of images.

The results of this study suggest that the use of the irreversible compression technique tested may be feasible for such tasks. A larger study with more rigorous methodology is indicated before such a technique can be widely applied. Other more difficult tasks that involve the detection of lesions requiring very high spatial resolution or subtle changes in image contrast also need to be specifically assessed.

Irreversible techniques are already finding wide application for teleradiology, where primary reading is not the objective, and access to the original image is ultimately available. Considerable debate has ensued as to the applicability of irreversible techniques to long term archival storage, and more controversially, to images for primary reading. Medico-legal factors related to the implications of deliberately discarding information, however meaningless, will undoubtedly play a role in determining the future applicability of irreversible compression, perhaps beyond what is scientifically sound. All modern digital acquisition methods, including magnetic resonance imaging, computed tomography, and computed radiography, involve a conscious decision to limit spatial and contrast resolution according to cost and time and patient discomfort and motion. Such new techniques as fast spin echo, GRASE, and keyhole dynamic imaging entail even more deliberate decisions to sacrifice information content to achieve a specific goal, and yet are readily accepted by the imaging

community once the artifacts involved are well understood. Compression techniques that alter images in similar ways do not seem to be received with the same liberal attitude in the present litigious climate.

V. ACKNOWLEDGEMENTS

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SESSION 7

RIS/HIS/PACS

Chair: Roger A. Bauman

An Integrated PACS-RIS: Experiences and Developments

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1 Introduction

Picture Archiving and Communication Systems (PACS) have been developed to cope with the constantly growing number of digital images being produced. PACS offers advantages such as reduced costs for archive space, faster transfer and handling of the images and capabilities of processing the digital image at the viewing stations¹⁻⁵.

At the Department of Radiology of the University of Graz an integrated PACS-RIS runs as part of the daily routine⁶⁻⁷. The PACS is connected with a Radiological Information System (RIS) so that the management of the image archive is done by the RIS. The PACS was installed in cooperation with Siemens Erlangen (Germany) and the operation in routine work has been studied for a period of several years. Software to improve the PACS handling and the image transfer to peripheral departments and image viewing at these places was developed. Since 1993, the PACS has been expanded by adding components based on the Siemens SIENET concept.

2 PACS components

The PACS in the Department of Radiology at the moment incorporates four CT-scanners, two MRI-scanners, one DSA and one ultra-fast CT as modalities. In addition, it includes a radiotherapy planning system, two reconstruction consoles and several reporting (SIENET DRC) and viewing consoles (PACS-View). Each department will be capable of producing hardcopies from the digital images by means of a SIENET camera server component (CS). One archive unit (SIENET ISA) with two jukeboxes (140 GB online) for optical disks (WORM) serves as longtime archive. The network hardware is based on FDDI and Ethernet. The PACS partially consists of a Siemens SIENET PACS and, on the other hand, of several components of an older Siemens PACS version (fig. 1). The SIENET modules are based on SUN SPARCstations, whereas the older parts are located on VAX systems. The older CT-scanners (still PDP11-based) are connected to the SIENET world via a gateway computer (μ -VAX II). The two MRI-scanners (which are manufactured by Philips) are connected using a SIENET „import spooler“.

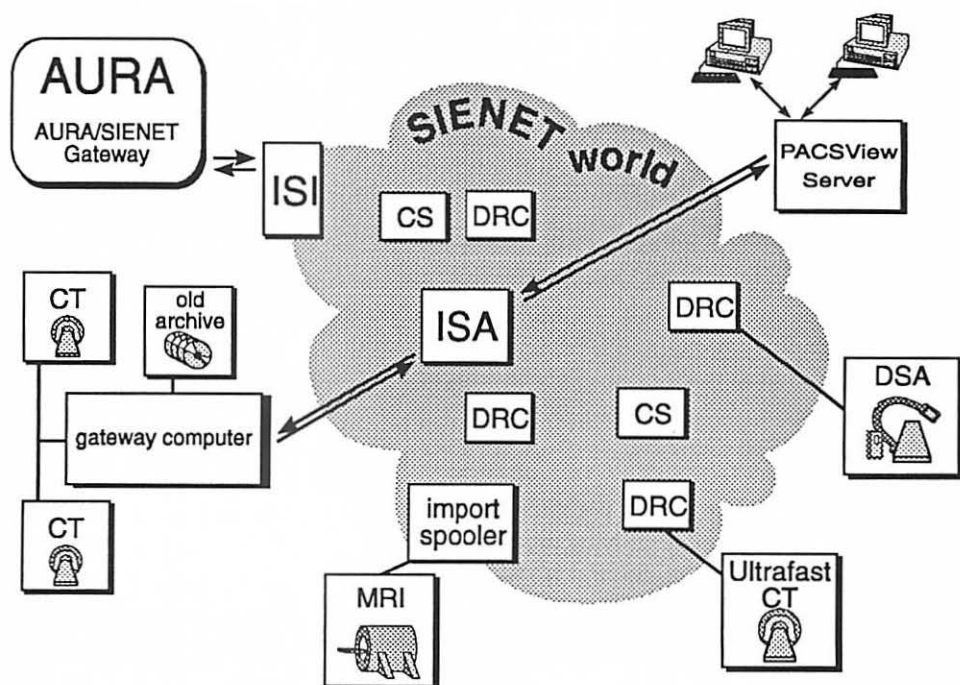


fig. 1: PACS components and their functional dependencies

3 PACS-RIS interface

3.1 RIS

In the Department of Radiology a RIS called AURA (AUtomatic Report Analysis) is in use since the middle of the seventies. This RIS was developed in-house⁸ and mainly consists of (index-sequential) RMS database structure with flexible record structure. AURA today includes about 120 terminals covering almost all aspects of patient admission, report writing, retrieval of previous examinations and scientific evaluations. All the examinations from CT, US, DSA, MRI and conventional radiography are stored in the RIS.

3.2 Structure of the Interface

The PACS is interfaced with the RIS so that the management of the image archive is exclusively done by the RIS thereby giving access to the images only via patient data. In the SIENET environment the link between the archive and the RIS is done by the ISI-Gateway (ISI: Information System Interface). The ISI-Gateway is based on a SUN workstation. The interface between AURA and the image archive is

realized as a software process (AURA Gateway Server) exchanging message files with the SIENET ISI-Gateway (fig. 2).

3.3 Function

The messages being exchanged between the SIENET Gateway Server and the ISI-Gateway are conforming with the ACR-NEMA standard. In particular, there are response and request messages for:

- Queries for AURA report texts
- Submission of image folder identification into AURA
- Retrieval of images

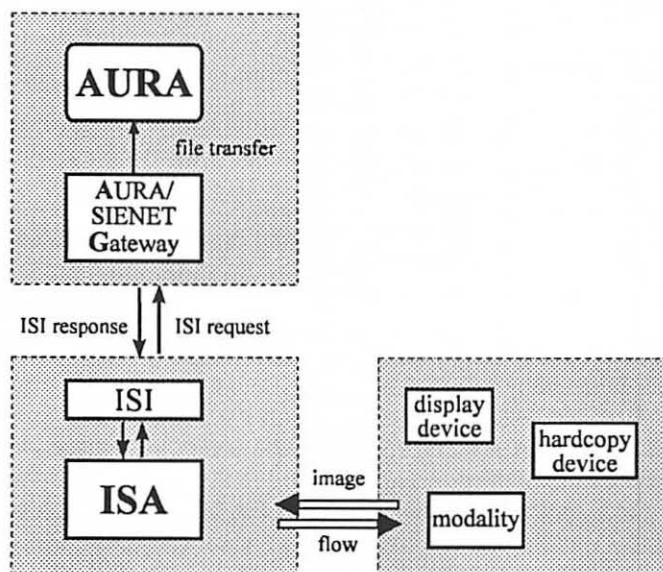


fig. 2: structure and function of the PACS/RIS interface

3.4 Operation

Between the ISI-Gateway and the AURA Gateway Server the Request and Response messages are exchanged by file transfer. Inside SIENET the messages are transferred by process communication.

Queries for report texts: During the image transfer to a reporting console, AURA is inspected for report texts of previous examinations. For this purpose a GET-REPORT-Request is send from the SIENET component (via ISI-Gateway) to the AURA Gateway Server. Amongst other things, this request contains patient identifying information and the logical address of the initiator. The AURA Gateway

Server searches AURA for examinations of the requested patient and sends a GET-REPORT-response which includes either the report texts or, in case of failure, the corresponding status back to the ISI-Gateway. The report request can also be initiated manually at any DRC reporting console.

Submission into AURA: Once the images of an examination have been stored on the ISA, the examination identification and the logical address of the ISA are inserted into AURA. Therefore the ISI-Gateway sends a GET-PAT-INFO-Request containing patient information as well as the required folder information to the AURA Gateway Server. The AURA Gateway Server stores the messages in a temporary file and sends a GET-PAT-INFO-Response about the successful (or failed) operation back to the ISI-Gateway. After the report text has been inserted into AURA by a secretary, the image folder identification and the logical address of the ISA are added automatically to the report text. The examinations in AURA are selected by patient name and birthdate (as there is no unique patient ID). As most of the modalities are not able to obtain patient identification data from the RIS, the data must be entered manually at the modalities and errors may occur.

If the patient data in the Request message from the ISI-Gateway and in AURA are not corresponding, the process which inserts the image folder identification into AURA tries in a second step to identify the corresponding examination using the examination number (which is unique but the search in AURA is much slower). If the link to AURA still cannot be done, the folder identification must be inserted manually.

Retrieval of images: As soon as the submission of the image folder identification into AURA is completed, the user has access to the images via the RIS. The retrieving is initiated by selecting a patient. Then a list of all the examinations of the patient is displayed. After having chosen an examination the user selects the target for the images from a menu. Next, AURA sends a message (including the image folder identification, the target address etc.) to the ISA. This communication is still based on direct process communication and not by message file exchange with the ISI gateway (as usual). In a future version the retrieval will also be done by means of file transfer. The retrieved images can be transferred to any DRC reporting console within the department, to the CT-scanners (where it is possible to make hardcopies) or to an image viewing console (PACS-View).

4 Routine operation

4.1 Handling

Most operations in the PACS are done automatically by software processes in the background. (These processes communicate with each other and execute tasks like transfer and conversion of images, management of databases etc.). A special interactive software process (PACS-Monitor) is used for the supervising of the PACS. The process monitors the background activities of the PACS and allows the user to get information about the status of the system at any time. To allow the routine

operation of the PACS not to depend on the permanent presence of an EDP-expert as far as possible, a rule-based expert system (OPERAS: OPERating ASsistant) is used for trouble shooting. Being started via the PACS-Monitor, OPERAS gains information about the current state of the PACS by opening a dialogue with the user, analyzing the situation via condition-action rules and finally either gives advice to the user or eliminates the troubles automatically. OPERAS implements rules for most of the troubles occurring during routine work of the PACS. At the moment, both the PACS-Monitor and OPERAS are limited to the old PACS.

4.2 Application

The PACS is used in daily routine for archiving and retrieving images. All the images from CT, MRI, Ultrafast CT and DSA are archived on the ISA. Images are sent across the different sub-departments of the radiological department. Although in our department the reporting from the digital diagnostic consoles is generally not yet accepted in clinical routine, several radiologists do begin to turn away from the traditional light boxes preferring the reporting on digital consoles. Within the PACS, the images from different imaging devices (such as CT, MRI, DSA) can be displayed simultaneously at one (multi-screen) reporting console.

An urgent clinical interest in PACS is the availability of images in places (neurosurgery, radiotherapy etc.) where they have not (or only with heavy delays) been available before. To give access to the images to anyone in such departments a PC-based „low cost“-PACS-Terminal software (PACSView) for image display has been developed in-house.

A special software (Process Configuration Editor) is used for the expansion of the PACS software structure in that sense that new processes (for the image transfer to and administration at each peripheral department) can simply be added to or removed from the existing configuration without changes to the remaining process structure. These processes are running on the VAX that is used as Server for the PACSView clients.

5 Conclusion

To the advantages of the RIS like sharing of data for patient care, fast access to the case history etc. the PACS adds the benefits of a compact and easy to handle image archive, fast access to the images and image processing capabilities at the image consoles.

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Integrated RIS/PACS Architecture for Daily Practical Reading (Utilization of HIS/RIS Information for Image Distribution)

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1. Introduction

During the past years, several efforts to transfer prototype PACS into an operational, clinically useful system have been made. Much work remains to be done before the system is able to completely replace conventional operating methods in a radiology department^{1,2,3)}

The problems to be solved primarily are the improvement of the connectivity between the modality and the system, the response time to access an image, and the on-line archive period of the image data base. However as the system is intended to support routine reading, dynamic adjustment of the image destination become required because the radiologists on duty is not at the viewing station all the time. This may cause overloading of the specific viewing station. So, some intelligent algorithm for image distribution to a multiple viewing stations becomes necessary.

In addition, because of the legal requirement in Japan that films be kept as an official archive of the image, it remains difficult for a radiology department to replace a conventional film-based system with an electronic system.

We have developed an integrated RIS/PACS system which supports examination, interpretation and management in the diagnostic imaging department, also considering dynamic control of image distribution. The purpose of this system is to provide a means to support immediate and chronological comparative reading without film file transfer. The system was installed at Toshiba Hospital in Tokyo in May 1993, concurrent with renovation of the hospital facilities.

The system consists of a radiology information management system (TOSRIM™) and an Image Management System (IMS). TOSRIM™ obtains ordering information, including patient and examination information, from the hospital information system (HIS), then transfers it to the modalities in the examination room as well as the system manager (SM) in the IMS. The modalities combine ordering information and images, then send them to the viewing stations via a file server, both in the IMS. The SM searches and retrieves the images of the previous examination using a priority code, then the images are sent to the viewing station so that immediate and chronological comparative reading can be performed there.

Using ordering information from HIS both in RIS and PACS, the effort required for inputting patient or exam information was reduced, while maintaining sufficient speed and accuracy of the system. To date, more than one thousand images, including CR,

CT, MR and NM, have been acquired, archived and interpreted every working day. The image transfer time from the examination to the viewing station is comparable to that of a conventional analog film system. The time needed for interpretation is also comparable to that when light boxes are used, but for the interpretation of some MR or CT images, it is sometimes longer. Note that analog film files continue to be sent to the viewing station until the system's file server has accumulated enough previous images.

In spite of these limitations, the vast majority of daily readings are performed with this system.

In conclusion, integrated RIS/PACS architecture seems to be acceptable for assisting daily practical reading.

In this paper, we discuss the features of this system, especially the dynamic control for image distribution and preliminary results based on workload measurements within a day.

2. Materials and methods

2.1 Overview of Toshiba Hospital

Toshiba Hospital is a 310-bed hospital with 800 outpatient visits a day. It is not only for Toshiba company employees, but is also open to local residents. It has 20 clinics and 3 examination departments (diagnostic imaging, endoscopy and ultrasound), and has an affiliated health care check facility.

The hospital, excluding the health care check facility, was renovated in May 1993, including the installation of an HIS for the entire hospital and an RIS/PACS in the Diagnostic Imaging Department. Expansion of the RIS/PACS to the wards and outpatient clinics is now being planned.

2.2 Diagnostic Imaging Department

There are four radiologists, including two senior residents, in the Diagnostic Imaging Department.

In preparation for the renovation of the hospital, the Diagnostic Imaging Department began interpreting almost all images produced by the department, while only 60% were interpreted previously. The integrated RIS/PACS system was installed with the expectation that it would support such daily reading by offering an immediate and chronological comparative reading function without film file transfer.

2.3 Objectives for RIS/PACS installation

There were two objectives for installation of the RIS/PACS at Toshiba Hospital. The first objective was to reduce the workload of radiology technicians by offering ordering information from the HIS, by automatically returning examination information to the HIS, and by keeping track of management information in the department.

The second objective was to support daily practical reading in the Diagnostic Imaging Department without film file transfer, by supporting immediate reading, chronological comparative reading and on-demand access to images.

2.4 Design requirements to support daily practical reading

2.4.1 Response time

Among the objectives stated in the previous section, we decided to place emphasis on supporting daily practical reading. Therefore, the time needed for CRT interpretation using the system must be comparable to (or preferably less than) that of a conventional system.⁴⁾

There are five items which affect the response of the system.

1)The ordering information transfer time from the reception desk to the examination room.

2)The examination time, which consists of the time for inputting patient/exam information to the modality and the examination time itself.

3)Image transfer time from the modality to the viewing station. In other words, the time between the end of the exam and the beginning of image interpretation. The time needed to retrieve previous images must also be considered.

4)Interpretation time, including preparation for displaying images.

5)Time needed for reporting.

The time required for each of the above items must be shorter or comparable to that of the conventional system.

2.4.2 Image distribution algorithm

Generally speaking, some priority control for distribution of images to a multiple viewing stations is necessary because immediate reading after the examination is required in some cases so that the patient can consult the referring physician at the outpatient clinic. Some kind of dynamic workload adjustment is also necessary. This is due to the fact that radiologists are not necessarily at the viewing station at all times and the throughput for reading may vary from individual to individual.

In Toshiba Hospital, there are three types of examination order coming from HIS; for urgent outpatients, for ordinary outpatients and for inpatients.

For urgent outpatients, interpretation has to be done as soon as possible because the patient is scheduled to return to the outpatient clinic again to consult with the referring physician on a same day. For other two groups, an interpretation is expected to be finished within a same day. Thus, the examinations for urgent outpatients must have priority for reading.

In addition, there are three viewing stations in this department. Therefore, images must be distributed adaptively to each viewing station so that all the required examinations can be read within working hours.

2.5 Integrated RIS/PACS architecture

The integrated RIS/PACS architecture makes it possible to meet the goals stated in the previous section (Fig.1)^{5,6)}.

The system consists of a TOSRIM™, which is our RIS, and an Image Management System (IMS), which is our PACS, interfacing with the modalities and connected to the HIS. TOSRIM™ obtains ordering information, including patient and examination information, from the HIS, then transfers it to the modalities in the examination room and also to the system manager (SM) in the IMS. The modalities combine ordering information and images, then send them to the viewing stations via the file server, both in the IMS. The SM searches and retrieves the images of the previous examination using priority code, then the images are sent to the viewing station so that immediate and chronological comparative reading can be performed there.

Using this architecture, the strategy described in the previous section can be implemented.

As a result, we achieved fast image transfer by employing a 100-Mbps LAN and 400-Mbps LAN for immediate reading. Then, migration of the image from the optical disk to hard disk is triggered by reservation information from the HIS for those patients who already have the reservations, and migration of the image from hard disk to the viewing station is triggered by patient arrival information from the reception desk at the Diagnostic Imaging Department. Preserving the window presetting information and layout information in the image file helps to shorten the interpretation time.

In order to achieve the above design features, connection and interaction of HIS, RIS PACS becomes necessary.⁷⁾

2.6 Configuration of the system

The configuration of the Toshiba Hospital system is shown in Fig. 2.

2.7 Dynamic control algorithm of image distribution

The algorithm for image distribution is as follows.

- 1)The destination will be the viewing station which has the least number of the remaining examinations.
- 2)When there is more than one viewing station which has the same number of remaining examinations, the destination will be assigned based on the time of image transfer to the viewing station.
- 3)The examination which has the priority is then listed at the first line of the waiting list for interpretation for each viewing station.

In order to determine the number of examinations left in the specific viewing station, the SM keeps track the number of examinations sent and the number of examinations interpreted.

Fig.1 Integrated RIS/PACS system

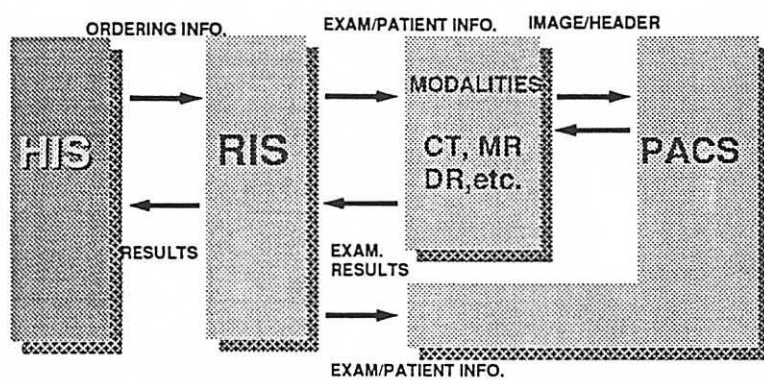
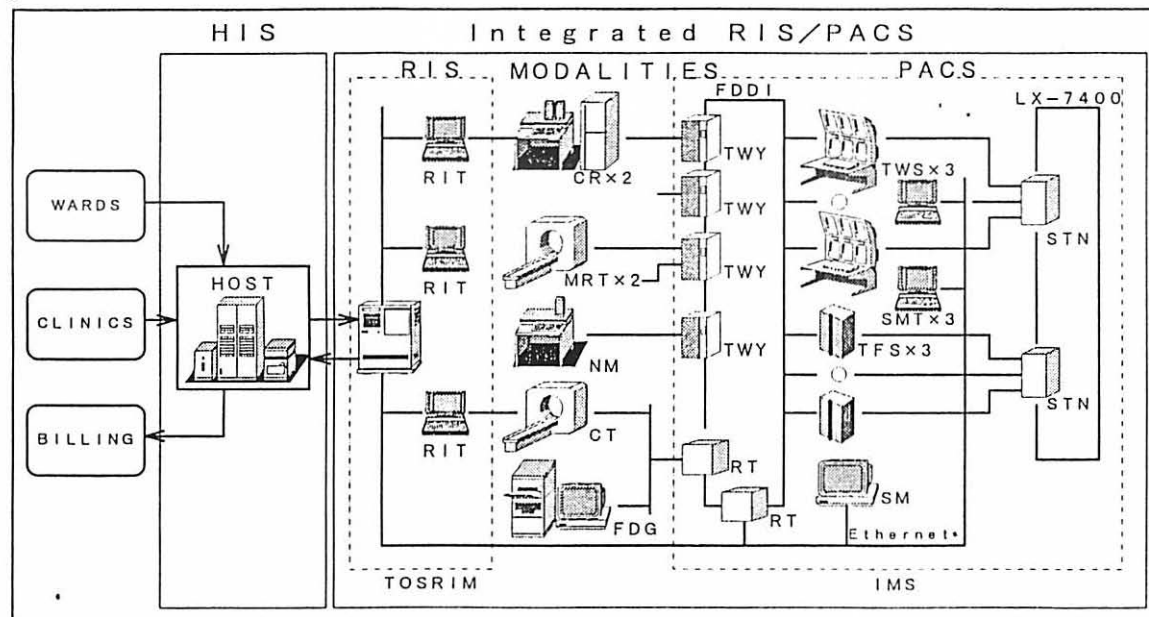


Fig.2 Configuration of the Toshiba Hospital System



SM :System Manager
 TFS:File Server
 TWS:Viewing Station
 TWY:Network I/F
 RT :Router
 RIT:Radiology Information Terminal
 SMT:SM Terminal
 STN:Station

2.8 Performance measurement

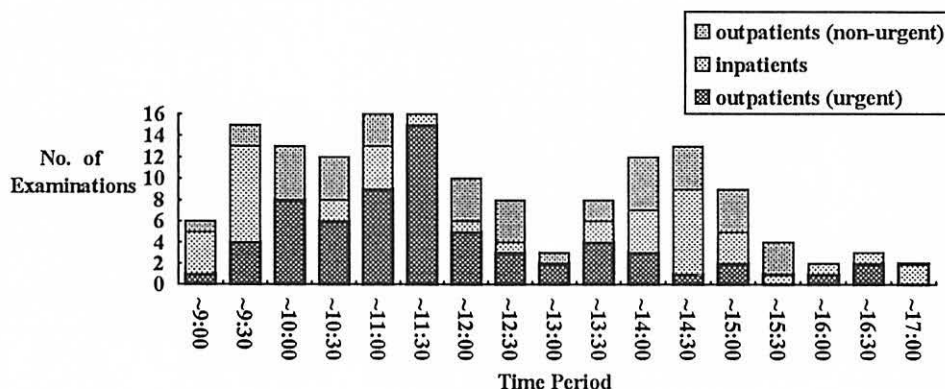
We have measured the number of the examinations interpreted for a specified time period within a day. They are categorized by the type of patient:outpatient(non-urgent),inpatients outpatients(urgent).

3. Results

(1) Since May 1993, over 400 thousand images have been interpreted, and 250 thousand images have been filed since Sept. 1993.

(2) Approximately 120 examinations on average have been archived, transferred and interpreted within the normal working period. As a maximum case, 152 examinations was processed on Nov. 4, 1993(Fig .3). All the reading work required on that day was finished by 5 o'clock.

Fig. 3
No. of Examinations for each time period on Nov. 4 1993



4. Conclusion

(1) The integrated RIS/PACS architecture used at Toshiba Hospital is acceptable for assisting daily practical reading.

(2) A more thorough study may be necessary to evaluate the system in detail.

(3) When a sufficient proportion of the previous images are in digital form, elimination of film file transfer in the Diagnostic Imaging Department is expected.

5. Future directions

In the future, we plan to integrate the reporting function into the RIS/PACS and to

distribute images to the wards and outpatient clinics, where the RIS/PACS and HIS workstations can be used in combination.

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The Integration Between PACS and HIS at the University Hospital of Lille

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I. INTRODUCTION:

Since 1990, the University Hospital of Lille has developed and installed an integrated Hospital Information System in collaboration with the DEC company, and a PACS among the 9 Hospitals on its campus. In the same time, it decided to work on an experimental PACS project concerning one Radiological department and two clinical units.

And today, the University Hospital of Lille participates in an European project called ISAR (Integrating System ARchitecture). There are two aims in this project:

- The first one is to integrate several AIM¹ prototypes and to show how they work on a real medical world.
- The second is to define a method for integration of AIM prototypes in some others environments.

One part of ISAR concerns the improvement of the existing PACS, in collaboration with DEC and MediCom Technologies, particularly by using different modules of EurIPACS (European Integrated Picture Archiving and communications Systems), and the implantation on a pilot site of a scenario about the integration of the both systems: PACS and HIS.

II. GENERAL DESCRIPTIONS:

II.1. The CHRU of Lille.

His capacity is about 4000 beds and it regroups 100 departments spread over 11 buildings which are connected all together in a network. This network was installed in 1991, and is using 660 kilometres of Ethernet network and 20 kilometres of Optic fibbers, 3500 connection sites have been designed, especially within medical units. The University Hospital of Lille is a multimanufacturers and multimodalities environment, and all the modalities are shared between the 6 radiological departments of the campus.

¹AIM: (Advanced Informatics in Medicine): European projects which include modules concerning transmission of patient-related information, images, multimedia and communication tools and video conferencing.

II.2. the PACS:

The PACS will allow radiologists, through radiological workstations:

- to make image processing and diagnosis on radiological patient record from dispatching devices to the different radiological units.
- to make a Computerised Imaging Summarised Record (CISR) for each patient with the report and a selection of the most significant pictures of the exams.

The workstations used for the exams diagnosis and the elaboration of the CISR have been developed with C and C++, OSF/MOTIF and XWindow languages. They works on UNIX platforms (presently DEC alpha platforms).

About the connections with modalities, 2 MR (one from G.E. and one from SIEMENS), 2 CT (ELSCINT), 1 DSA (PHILIPS) and 1 Digital Radiography (G.E.) will be connected this year.

The protocols of communication are based on TC/PIP. And DICOM 3.0 has been chosen for the data structure and encoding definition and the message exchange.

About the PACS management, the solution will be given by an EurIPACS product. This product concerns an Image Server which is an object oriented view of networks, services and data management, encapsulating the key issues of second generation PACS. The Object Server module of this Image Server is a distributed database developed with an SQL (Standard Query Language) based commercial database.

II.3. The HIS:

The HIS provides clinicians with basic software applications, including communication facilities, common patient record and telecommunications possibilities.

It is based upon a client-server architecture using:

- PC computers as terminals.
- UNIX machines (DEC alpha systems) for departmental machines.
- Main frames for archiving data and centralised applications.

the software architecture is realised with:

- ORACLE as data base management system.

The main idea was to build it on a kernel made with a tool kit which allows the development or the integration of every kind of hospital applications and ensure their relationship. This tool kit, called OTALIA, was developed with UNIFACE as a fourth Generation Language, by the users themselves in collaboration with DEC. It works on an Windows and XWindow environments.

OTALIA defines the communication and the integrity of the information. Particularly, there is one application concerning the management of medical and administrative information of the patient and which have been developed with OTALIA: the Common Minimum Patient Record (CMPR).

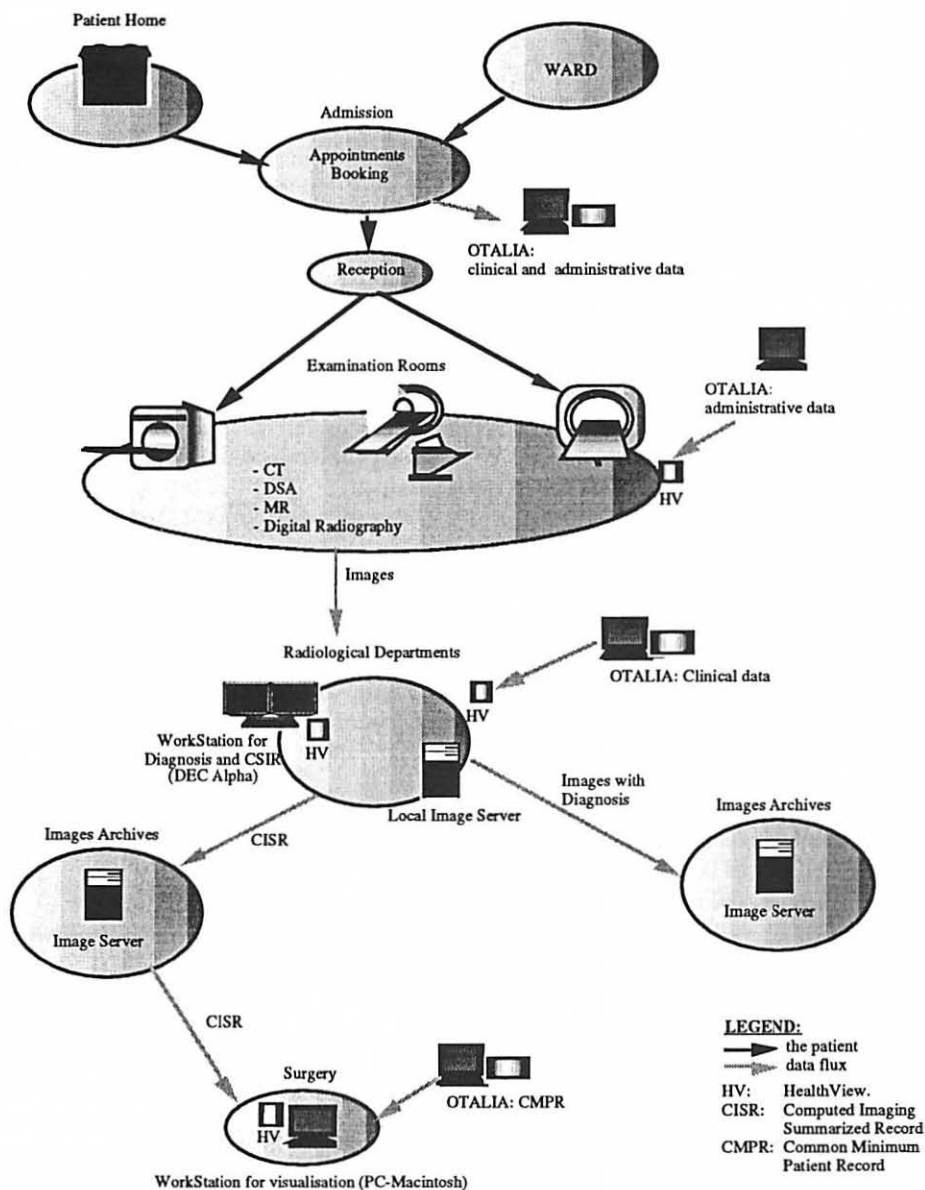


fig 1: The integration between PACS and HIS at the CHRU of Lille

III. HealthView: The Bridge between PACS and HIS.

Of course, it's obvious that the main interest of the development of such systems, PACS and HIS, is to be able to transmit the entire set of the patient's information whatever the information comes from, and to avoid having several copies of the same data in the different systems (demographic data for example).

In particular, the University Hospital of Lille wanted to lay emphasis on three points:

- the administrative record of each patient must give automatically the information about the patient identification to all the other kind of records.
- To make a diagnosis on an exam, radiologists need to obtain on their radiological workstation the clinical data of the patients.
- the CISR must be integrated to the CMPR, because both clinicians and radiologists must have always the access to the Radiological history of the patient.

(The fig 1 gives a general description of the scenario the PACS/HIS integration chosen by the University Hospital of Lille.)

The issue was to find an answer to these problems, which interfaces all the systems without any changes on the existing products.

In that way, the University Hospital of Lille makes its choice on HealthView.

III.1. What is HealthView?

HealthView is a DEC software platform, which provides a base level of functionality as the foundation of a systems integration project. Its aim is to ensure the relation ship between the different departmental systems of a healthcare environment and the different applications of the global users (Physicians, administration, ...).

It works whatever the operating system (DOS, UNIX, VMS, MacOS, ...) and network management (TCP/IP, DECnet, Novell, ...) used by departmental systems and global users.

It is based upon international standard for electronic data exchange in healthcare environment (HL7, DICOM 3.0) and also has facilities to support alternative standards and integration of non standards based systems.

There are 2 major components in HealthView:

- The Connection Engine, released on OSF/1. It is composed of the Intelligent Agent Modules which provide communication between applications and the routing/translation mechanism. This is the platform for connecting all applications and frameworks.
- The connection Manager, MS-Windows based manager for the connection engine, concerns in the first hand, the configuration and the management of the Intelligent Agent Modules, in the second hand, the monitoring and the management of the Connection Infrastructure and Intelligent Agent Library.

III.2. HealthView in the University Hospital of Lille.

In Lille, in the PACS module of the ISAR project, HealthView will be used to make the link between (see fig 2):

- OTALIA applications and the different Image Servers of the PACS to ensure the integrity of the demographic data for example.
- the modalities and the different Image Servers, to make the translation of the multi-vendors data formats into DICOM 3.0
- the radiological and clinical workstations and the different Image Servers, to manage images queries.
- the radiological and clinical workstations and OTALIA applications, to manage general information queries about patients (clinical data, administrative data, ...).

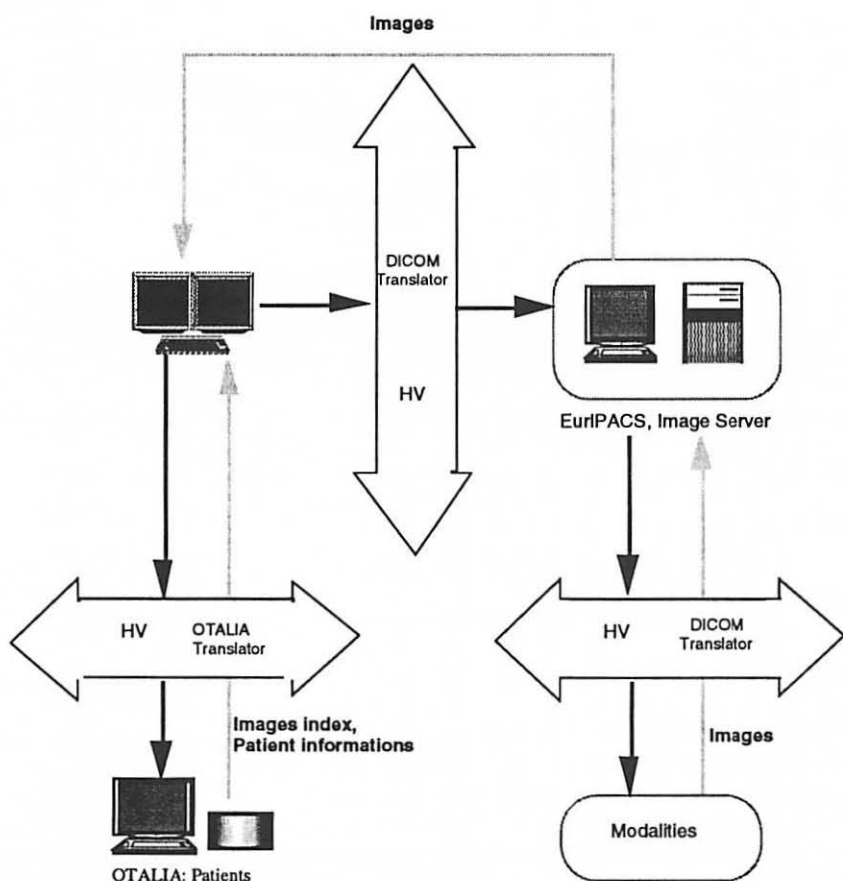


fig 3: the use of HealthView at the University Hospital of Lille

The principle is to create one Intelligent Agent Module (IAM) per application whatever the number of destinations the data will be sent to. These applications could reside anywhere and run on any type of platform. they are connected together through the Health View Connection engine via the IAM.

The Connection Engine is Configure through a management console, the HealthView Connection Manager.

The AIM has all the information required for data to flow from/to the application (see fig 3).

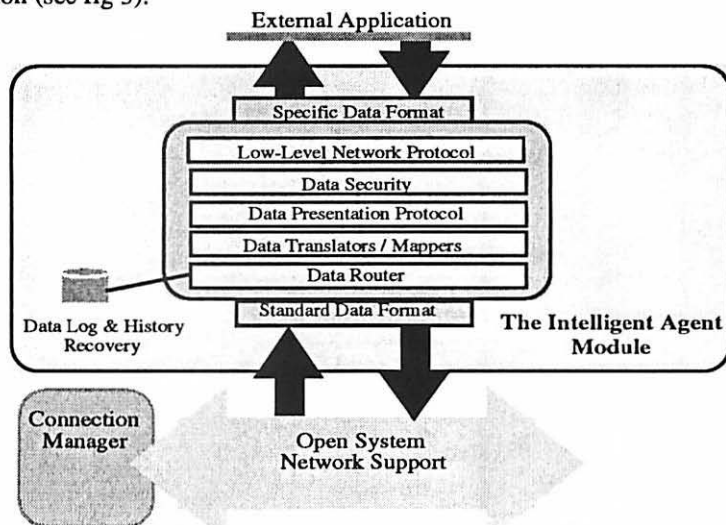


fig 3: The general structure of an Intelligent Agent Module

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Le Dossier Résumé d'Imagerie est-il un mythe ou une Réalité?:

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Radiological Services Automation: PACS-HIS Integration

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1 INTRODUCTION

At the Istituto Nazionale Tumori (INT) in Milano a Hospital Information System (HIS) has been developed in the Department of Clinic-Scientific Informatic (DICS). Also, a PACS module SIENET (SIEmens Medical NETworking) has been in operation since the end of 1992.

The integration/interface of the INT-HIS and the PACS is still in progress with the objective to obtain a master system with expanded capabilities to manage, synchronise and maintain the alignment between the two systems. Further the DICS intends to integrate into the system a tape library with several TBytes on line for image back-up and also an automated voice reporting system with the capability of speech recognition. In this way the final product will be an integrated radiological system with extensive capabilities to manage images, clinical data as well as dictated reports.

2 RADIOLOGICAL WORK LOAD

Examin. Type	Exam. Count	GByte/year
Chest	28.251	387
Bone	15.049	656
Breast	13.248	613
Gastro Instest.	3.202	166
Genito Urinary	4.944	103
US	5.452	27
Angiography	434	21
CT	4.335	64
MR	3.572	17
NM	8.300	8
TOTAL	86.787	2.061

Tab. 1: Official data relative to 1992

Based on the official data from 1992, in the Department of Diagnostic Imaging at the INT, which includes five Radiological Departments and one Nuclear Medicine, more than 86.000 examinations with about one million medical images were produced during that period (Tab.1). If all these images were acquired digitally, the digital memory requirements would exceed 2 TBytes.

It's proposed that the amount of the radiological examinations will continue to increase over the next years.

3 PACS SYSTEM

3.1 Networks

PACS includes one Ethernet and one FDDI LAN. Both networks are in star-shaped physical layout, utilizing fiber optical cables.

The communication takes place via respectively PACSnet-10 (SPI application protocol, DECnet transport protocol and physical IEEE 802.3) for Ethernet and PACSnet-100 (SPI application protocol and TCP/IP) for FDDI.

3.2 Connected Modalities

The image sources connected with the PACS system are a Siemens CT DR-H and Siemens MR GBSII. The images acquired with these modalities can be forwarded to the PACS from the satellite consoles, through a simple command without interfering with the execution of on going diagnostic examinations. Unfortunately the existing imaging devices are of old design: for this reason each modality addresses its images to a dedicated Gateway which translates the images into the ACR/NEMA-SPI format, used inside PACS. Images are then automatically routed to the diagnostic PACS consoles.

A film digitizer from Lumisys (Lumiscan 200) is also connected to the PACS so that images acquired from modalities not connected to PACS or produced outside the hospital, can be entered into PACS. The digitized images are complemented with anagraphic and technical data at an interfacing workstation, and then from there they are transmitted to the PACS via the Ethernet LAN.

3.3 Workstations

The PACS of INT includes two Diagnostic Reporting Consoles (DRC) with the trade name of Magic-View 1102. They are connected to the modalities through the Ethernet LAN and they are used for image visualization, image processing, reporting and printing.

Regarding the hardware, each DRC is based on a SUN SPARC 2 station with some additional boards. Each one has a 2.6 GByte Hard Disk, 214 MByte RAM, two high resolution monitors (1280x1024) with 256 grey scale levels, a refresh frequency of 72 Hz non-interlaced and a brightness of ap. 600cd/m².

Each station is connected both with Ethernet and FDDI LANs but doesn't act as a gateway.

3.4 Digital archiving

Image storage in PACS is done at four levels: local, remote, juke-box, off-line.

"Local" means the DRC hard disks.

"Remote" means the RAID (Redundance Array of Inexpensive Disks) hard disks in the central archive, called Information Storage and Archiving System (ISA). This disks has a capacity of 5,4 GBytes.

"Jukebox" means the WORM optical disks inside the jukebox, which is SCSI connected to ISA. The jukebox can host 56 WORM disks 5,25" with 625 MByte capacity each. The images in the juke-box are stored in a compressed format with a reversible algorithm and a 2,5:1 ratio. In this way the capacity of the jukebox exceeds 90 GBytes.

"Off line" means the WORM optical disks outside the jukebox.

Image folders can be viewed and processed only if they are local.

Images coming from the modalities are memorized directly in the local storage.

Only those folders previously archived in the ISA can be retrieved and examined on both the PACS consoles, even simultaneously.

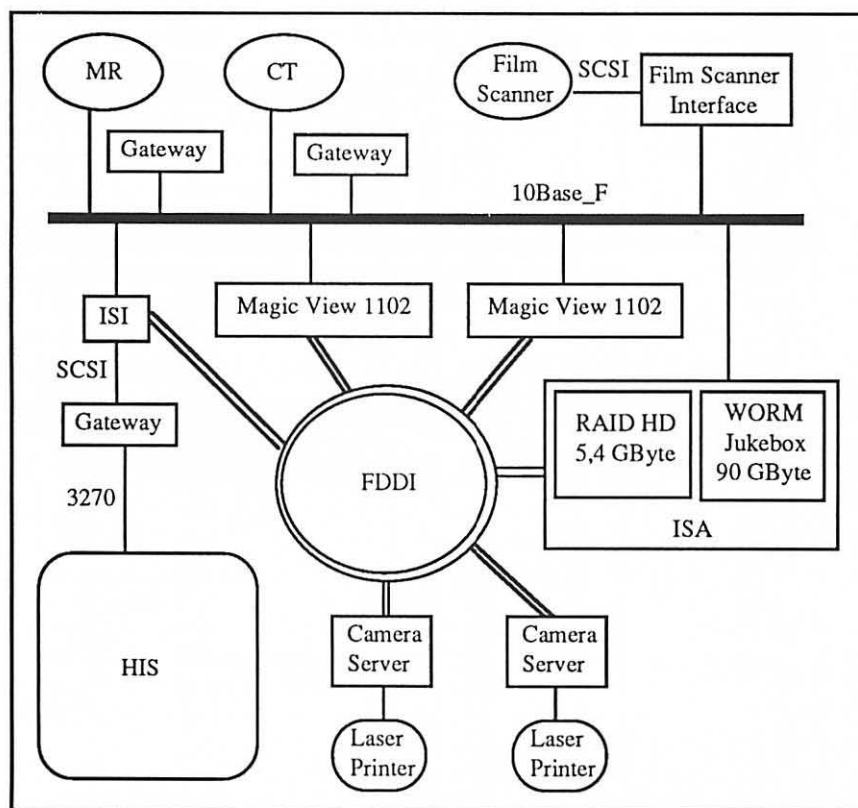


Fig. 1: PACS layout

Transfer of images from the RAID HD to DRC takes about 1'30" for a folder of 50 CT images (512x512x16 bits each), while about 4'30" are needed to retrieve a folder of 50 CT images from the juke-box.

3.5 Laser printers

Two laser printers are connected with the PACS (Konica Li-10A and 3M M 959XL), each one close to a diagnostic modality. The connection runs through a Camera Server (SUN SPARC 2) which locally supports a dedicated software to manage the printing queues and select and modify the LUT.

The "print" command is entered at the Magic-View console where it is also possible to select, modify and store the printing parameters (i.e. film format, number of images for film, number of copies, etc.).

4 HIS SYSTEM

The Hospital Information System (HIS) has been developed internally at INT, partly on an IBM 370 platform (VM/SP, SQL/DS, ISPF, REXX, and 3270 communication protocol) and partly on Personal Computers (DOS, CLIPPER) connected to the mainframe in a client/server architecture. The mainframe acts mainly as data base manager while PCs support the application front-end.

The database manages clinical information and scheduling for patients under treatment or examination, and provides historical data of previous contacts with patients.

RIS subsystem is part of a general scheduling, reporting system of HIS and regulates data flow from examination request, scheduling, execution and final reporting. The system allows entry of patient information into the data flow independently at each step (request, scheduling, execution, reporting, invoicing) needing only the prerequisite of patient registration.

PACS and RIS patient registration data can be aligned at two different times, but in the reporting phase at RIS, patient data on PACS and on HIS must be aligned.

During reporting the list of coded examinations taken from the requests can be updated and linked to one or more reports. The examination code list is also used for invoicing.

5 PACS/HIS INTERFACE

The standard used inside PACS is the ACR/NEMA-SPI and it extends its definitions also in the PACS-HIS information exchange.

It is also similar to the concepts expressed in part 7 of the DICOM standard. It's important to stress that DICOM "is developed in liaison with other standardization organizations including CEN/TC251 in Europe and JIRA in Japan, with review also by other organization including IEEE, HL7 and ANSI in the USA."

The ACR/NEMA-SPI uses the Services-Objects-Pair (SOP) concept like DICOM does. Therefore it's possible in the future to easily migrate towards DICOM.

Because the HIS system has been "home" developed and because it was born before the standards, it speaks a proprietary language. There is a module between PACS and HIS, called Information System Interface (ISI), which has the task to translate ACR/NEMA-SPI messages into HIS language and viceversa.

Up to now the information exchanged through ISI, between PACS and HIS, are request and response messages to reports, worklists, and patient-data-update.

The communication between PACS and INT HIS is ready but at the moment is not yet used in the routine clinical work because it is in a testing phase.

5.1 Patient Data Update.

The database inside PACS is filled with data extracted from the image headers. Therefore only data which are provided by the modalities with their image header are available on PACS. These data are not sufficient. Some important items are missing and other items may be wrong or misspelled. Therefore PACS makes a request to HIS for receiving additional information when a new image folder arrives inside PACS.

5.2 Worklist.

PACS uses the HIS worklists (one for each modality) to perform the preload of old folders from the archive. With this approach these old folders will be available when they are needed.

5.3 Report.

Report functionality allows to see on the workstation screens, simultaneously images and HIS reports.

5.4 Patient Data Check.

The adding of a new object in the PACS-HIS communication regarding the data-patient-check is in discussion.

The main goals of this new function are:

- 1) To guarantee the consistency of the patient identification in the two systems. This means that no image folder should be archived on ISA if SIENET Patient-Name, Patient-ID, Patient-Birthdate are different from those on HIS.
- 2) To create a link between any image folder archived on ISA and the corresponding HIS information stored on the HIS database. For each image folder stored into PACS archive several information exists on HIS database:
 - Patient ID
 - Patient Name
 - Examination Date
 - Modality
 - Requesting Ward
 - InPatient/OutPatient Qualifier
 - Reporting Physician
 - Examination Codes (Organs)
 - Report(s)

HIS data relative to one or more examinations should be linked to the corresponding PACS image folder.

Since November 1993, on PACS at INT a semi-automatic routine is used to check the identification data of the patients. This program identifies if patient data on PACS are not equal to those on HIS so that the users have the possibility to

correct the mistakes. Obviously this situation appears to be unsatisfactory due to the fact that data consistency is committed to the user's good will.

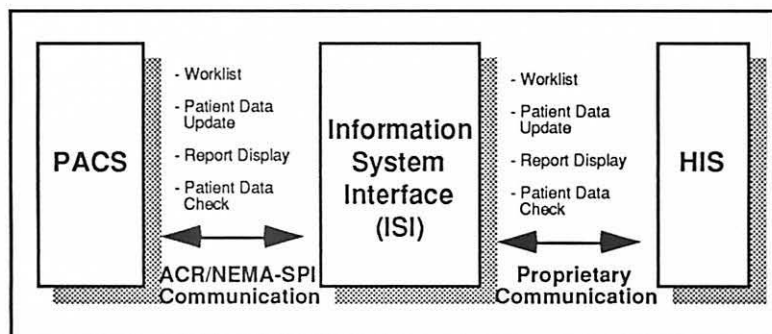


Fig. 2: PACS-HIS communication

To avoid such dependencies some mechanisms are going to be implemented.

1) To force the check of the PACS data (manually inserted on the modalities by the radiological technician), relative to any image folder which has to be archived, against HIS data. This data are:

- Patient-ID
- Patient-Name
- Patient-Birthdate
- Examination code 1, Examination code 2, ... (Organs)
- Reporting Physician
- Requesting ward
- Inpatient/Outpatient Qualifier

Every item may be already "HIS-like" (if for instance it comes from an HIS worklist or is equal to an item in the HIS worklist) or may be transformed in "HIS-like" status as follows:

Patient-ID, Patient-Name and Patient-Birthdate elements should come from a worklist item opened for selection at the moment.

Equally other elements should be selected from code tables of HIS.

Only when PACS data are reduced to "HIS-like" status the archiving of the image folder will become possible.

2) After the archiving of any image folder in the PACS archive, an acknowledgement record containing the following information will be sent to HIS for HIS database update:

- Patient-ID
- Patient Name
- Organs (Examination Codes)
- Modality
- Requested Ward
- InPatient/OutPatient Qualifier
- Reporting Physician
- Examination Date
- Folder-ID

7 CONCLUSION

Since the availability of the last software for PACS management, all the CT and MR diagnostic examinations as well as some digitised images were archived into the PACS.

Up to March 30 1994, 4023 patients were stored in our PACS, with a total number of 7875 examinations and an image count of 250.535 (32 images average for each examination) (Tab. 2). Because the compression algorithm has been working since some months, the optical disks filled are till now 110.

Modality	Exam.	Images
MR	3.368	118.010
CT	4.407	132.197
Film Scanner	100	328
Total	7.875	250.535

Tab. 2: Statistics

The described project is a testing module for the entire hospital.

For the future further expansions are planned, with the goal to complete the development and the implementation of PACS and HIS:

- 1) Connection of the tape library for image back-up;
- 2) Recently several speech recognition systems have been developed. Some of these are dedicated to the medical environment and appear to be sufficiently reliable with more than 95% of the words being correctly identified.

In our Department, the physicians who tested the devices, positively considered their use in order to speed up the reporting cycle and to optimize the management of our Radiological Departments.

After this experience we are now considering the full integration of these devices into the CT and MR reporting sites, connecting them to RIS on the IBM host.

- 3) Step-by-step connection of the other diagnostic modalities;
- 4) Connection of the Department of Radiation Therapy;
- 5) Gradual adding of viewing consoles in non radiological wards.

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Categorization of Existing Digital Medical System Interfaces

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Introduction

There is a demand within the medical community to have access of the patient information scattered in various digital imaging equipment. To meet this demand, the committee of Digital Imaging and Communications in Medicine (DICOM) established a standard to support open systems interoperability among different manufacturers' scanners. Most health care institutes, however, have a large inventory of image scanners in use based on "closed" architectural designs. These scanners cannot be easily modifiable to meet the DICOM specifications, and upgrading or replacing them would be costly. To retain the services of the existing scanners and to achieve open system interoperability environment is a challenging issue.

Since 1983, our group have been active in the design and implementation of Picture Archiving and Communication Systems (PACS) in two leading medical centers, UCLA and UCSF. We have gained much working experience to integrate several imaging scanners of major manufacturers into our PACS environment. Based on this experience, we classify the existing architectures of interfacing image scanners to acquisition computers into five categories and discuss their pros and cons with respect to the costs, rate of data transfer, ease of implementation, and system portability. In addition, we suggest a few PACS design considerations which are based upon the DICOM standards, so that the designed PACS can support open systems interoperability among other medical imaging systems and PACS'.

A General Interface Architecture

Generally speaking, the PACS image acquisition system consists of three major components: (1) a medical imaging system, (2) a computer system that acquires images from the imaging system (i.e., an acquisition computer), and (3) an interface mechanism (hardware and software) between the imaging system and acquisition computer. Specifically, this broad architecture can be further divided into five models: (a) sequential chain, (b) direct interface, (c) memory access, (d)

shared disk, and (e) interconnected network. We describe the configuration and the characteristics of each model in the following.

Sequential Chain Model

Sequential chain model is the PACS acquisition computer that links a medical imaging system through a chain of interface devices. An example of the sequential chain model is the IDNET-1 solution provided by General Electrical Medical Systems (GEMS) to acquire CT images from the GE-9800 CT scanners about five years ago. Figure 1 shows the schematic diagram of IDNET-1. The parallel peripheral interface (PPI) board, residing in the scanner system, functions as a virtual magnetic disk driver that reads the data from the disk of the scanner to one of the network interface equipment (NIE) units, which is located next to the scanner system. At the NIE-1 node (see Figure 1), the data is encoded into an ACR-NEMA (the American College of Radiology and the National Electrical Manufacturers Association) format. For this particular example, NIE-1 communicates with NIE-2 using a GE proprietary data transfer program and a dedicated Ethernet link within the GEMS proprietary network.

NIE-2 is another node in the GEMS network and has a standard ACR-NEMA output (50-pin connector) to an ACR-NEMA interface board. During our implementation, the only ACR-NEMA interface board available in the market is PC-based. Hence, we used a PC/AT as the last unit of the interface chain. This PC/AT transmits the image data to the acquisition computer in the PACS network with a PC Ethernet board.

Since this configuration requires several interface units, the cost of the interface is high and the connectivity is complicated. Further, it is difficult to measure the elapse time spent in each interface unit for determining the data transfer performance. The observation, however, is that the data transfer between the PC/AT and the PACS acquisition computer is most time-consuming. We have measured the data transfer rate between a PC/AT and a Sun minicomputer 3/260 (disk to disk) is about 50 KBytes per second [1]. The sequential chain model has the disadvantages of being costly, complex, and low transfer rate, but it was the only solution to acquire the images from the GE-9800 CT scanners to the PACS five years ago.

Direct Interface Model

Direct interface model is a PACS acquisition computer that connects a medical imaging system through a standard electronic interface board. Examples for this model are a DR11-W interface of an Abe-Sekkei (AS) film laser digitizer (model 2904) and the data acquisition system manager (DASM), which is a SCSI device, of a Fuji computed radiography (CR) reader. Figure 2(A) and 2(B) show the interface configurations of these two imaging systems respectively. In

Figure 2(A), the quantized data are buffered in the DR11-W board. The buffer size in our application is 32 KBytes. Whenever the buffer is full, the data are then archived to the disk of the PACS acquisition computer. In addition, the AS film laser digitizer can also be interfaced by a SCSI interface. The Fuji CR reader in Figure 2(B) outputs digitized data through a set of RS485 cables, including a RS422 parallel bus cable for pixel data transfer and a RS232 serial bus cable for text information communication, to a memory buffer in the DASM. The PACS acquisition computer then pulls the data into its SCSI disk.

The advantages of this model are: the interface units are commercial products, the connectivity is simple, the cost is affordable, and fast data throughput. We measured the rate of data transfer of both configurations described in the Fig. 2(A) and 2(B). The transfer rate between the AS film laser scanner and the SCSI disk of a Sun SPARC LX computer is greater than 1.2 MBytes per second. The data throughput between the Fuji CR reader and the SCSI disk of the SPARC LX is approximately 530 KBytes per second. The problem is that the acquired image data is not DICOM or ACR/NEMA compatible.

Direct Memory Access Model

Direct memory access model is that a PACS acquisition computer connects a medical imaging system through a dual-port system RAM (random access memory) [2]. Imatron Cine CT scanner utilizes an interface product called MegaLink to acquire images from the Cine CT scanner. The MegaLink is an example of the direct memory access model, and Fig. 3 shows its configuration. The two MegaLink bus adaptor boards are linked by a pair of 25-foot cables. The adaptor board installed in the Fast Reconstruction System (FRS) of the Imatron CT scanner contains 1-MBytes dual ported RAM. The memory is accessible by both the FRS and the PACS acquisition computer. The FRS stores the study information header and reconstructed image data in this memory area. The PACS acquisition computer accesses the data via the MegaLink bus adaptor board and the cables using the direct memory access mechanism. A program uses a simple semaphore-based interlock protocol to synchronize the data transfer between the two computer systems.

Intuitively, one can see that the direct memory access model provides fast data throughput because the data transfer is very similar to the scenario of writing data from the CPU memory of an acquisition computer to its own disk. Our measurement for the configuration in the Figure 3 is greater than 1 MBytes per second.

Shared Disk Model

Shared disk model is that a PACS acquisition computer either connects or mounts a common accessible disk of a medical imaging

system. Examples of this model are GEMS' IDNET-2 and Sun Microsystems' network file system (NFS) configuration. Figure 4(A) illustrates the configuration of the IDNET-2, where a dual-ported SCSI disk is connected with both the GE-9800 CT scanner system and the PACS acquisition computer. Figure 4(B), on the other hand, shows the NFS configuration, where the disk within the imaging system is mounted by the PACS acquisition computer through NFS. Both configurations, Figures 4(A) and 4(B), share a common feature, i.e., data available in the disks of the imaging systems are also available in the acquisition computer at the same time.

Among all the interface architectural models introduced in this paper, the shared disk model has the best image data availability. This is because no image data propagation is required in this model. NFS configuration, however, suffers a major disadvantage. In NFS, any interaction with image data from the acquisition computer must require the resources of the network and the imaging computer system at the same time. This is an undesirable interruption to the operation of the imaging system; especially, in the situation when the imaging system is in busy use.

Interconnected Network Model

Interconnected network model is that a PACS acquisition computer and medical imaging system host computers are connected in a network and communicate through standard communication protocols. GEMS' newer CT and MR scanners, such as Hi-speed Spiral CT and Signa-5X MR scanners, are designed based on this model. Figure 5 shows the configuration of a GE imaging medical systems' interconnected network currently installed in our Radiology Department. The network follows the Open System Interconnection (OSI) standard layers specified by the International Standards Organization (ISO) [3]. The layers of physical and data link are Ethernet, the network layer is Internet Protocol (IP), and the transport layer is Transmission Control Protocol (TCP). For the application layer, the GEMS' proprietary communication programs based on TCP/IP and a File Transfer Protocol (FTP) are currently used. We will soon replace this GEMS program with a program using the DICOM protocols once the standard is available.

Since the interconnected network model follows the industrial standards, its advantages include affordable cost, portable components, and easy implementation. In our experience, the major effort to configure this model is lay down the network infrastructure. For an existing networking environment, there will be minimal effort require to implement this interface model. As far as the speed of image data transmission concern, we measured that the disk-to-disk performance ranges from 100 KBytes per second to 400 KBytes per second. The result is so wide ranged because it depends on: (1) types of computing

systems (both the imaging system and acquisition computer), (2) types of system disks, (3) utilization of the network, and (4) workload of the computing systems.

Conclusions

In summary, we list the preference ordering of the five interface models according to the four parameters, i.e., costs, rate of data transfer, ease of implementation, and system portability, in Table 1.

PACS is an essential ingredient for the realization of digital radiology environment. One crucial task is to integrate various types of image scanners and modalities into the open system PACS network. Existing scanners, however, are developed based on closed system design and do not communicate with one another. In this paper, we categorize the current interface architectures and discuss their strengths and weakness, as well as the suitability of system integration. We believe that this is the first attempt to classify interface mechanisms of image acquisition systems. This paves the way for systematic modification or extension of the current scanners and fuse them into one uniform PACS platform.

In the near future, PACS will become a medical imaging input system to other PACS'. To ensure PACS possesses the open systems interoperability, we suggest the following considerations in designing and implementing a PACS:

(1) For acquired image data (or object) following the Information Object Definitions and the file format defined in the DICOM, PACS remains the object as it is.

(2) For acquired image data not following the Information Object Definitions and the file format defined in the DICOM, PACS image acquisition systems need to convert the object based on DICOM standards.

(3) To transmit image data out to other PACS', PACS image data sending programs should follow the definitions in the DICOM upper layer protocol for TCP/IP.

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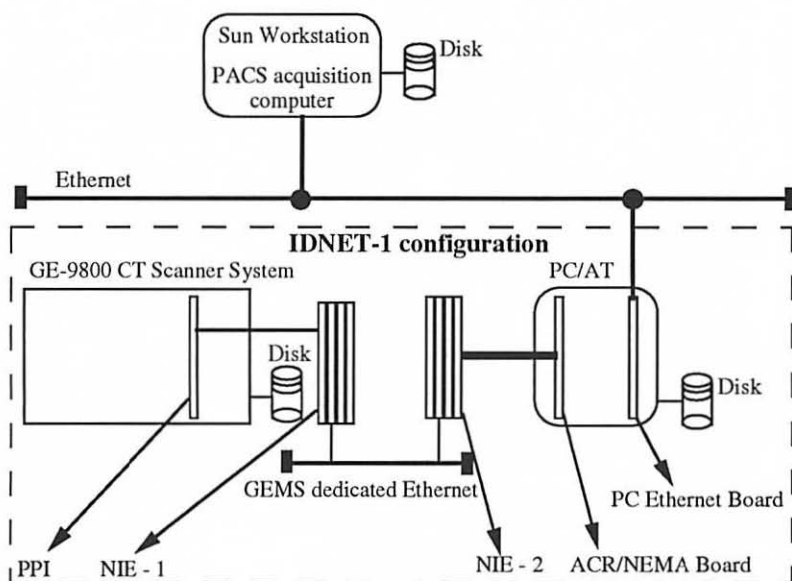


Figure 1 - The configuration of the IDNET-1 which we use it as an example of the sequential chain model. Image data propagate through the PPI, the NIE-1, the GEMS dedicated Ethernet, the NIE-2, the PC/AT, and the PACS acquisition computer.

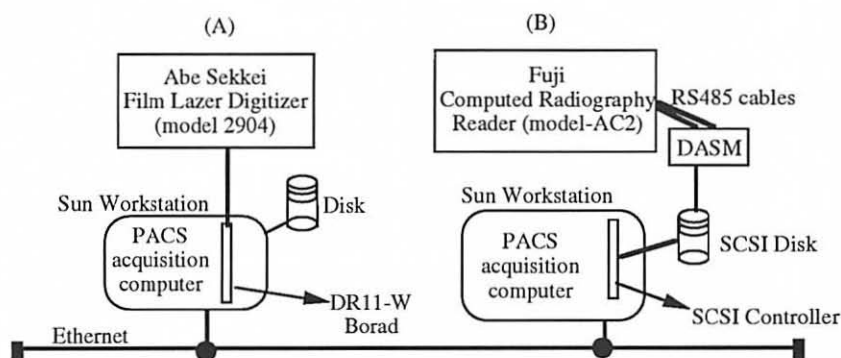


Figure 2 - (A) The diagram shows that the DR11-W interfaces the Abs Sekkei film laser digitizer to the acquisition computer. (B) The diagram shows the DASM interfaces the Fuji CR reader through SCSI controller to the acquisition computer. Both configurations are classified into direct interface model.

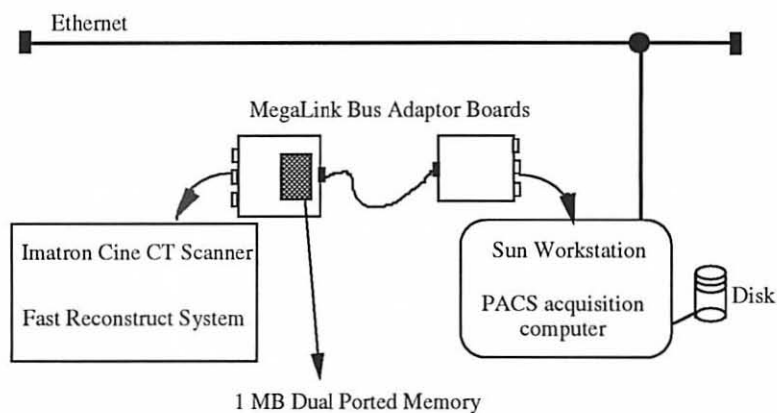


Figure 3 - The diagram demonstrates the MegaLink connects the Imatron Cine CT Scanner and the acquisition computer. Image data are through the dual-ported memory acquired by the acquisition computer.

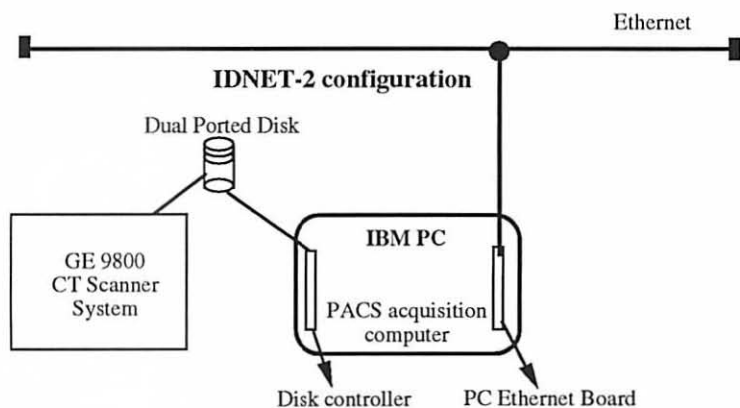


Figure 4(A) - The diagram shows the IDNET-2 configuration. Reconstructed CT image data are stored in the dual-ported disk which is also accessible by the acquisition computer.

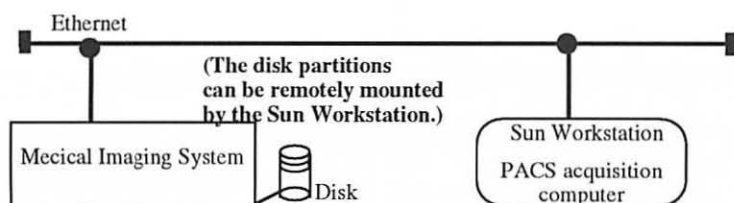


Figure 4(B) - Another example of the shared disk model. The Sun workstation remotely mounts the disk which is physically with the medical imaging system. As a result, the acquisition computer can access the image data in the remote disk.

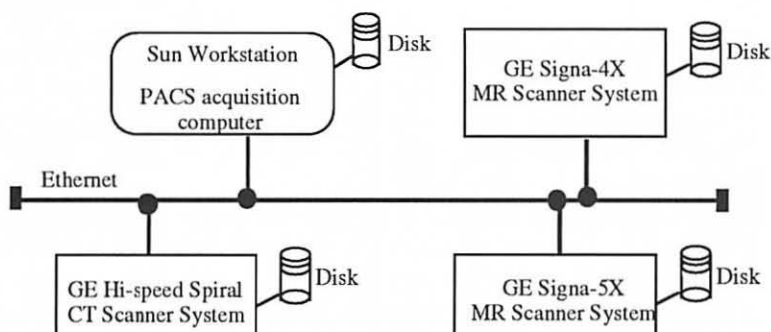


Figure 5 - The diagram shows the interconnected network model. The acquisition computer acquires images from the medical imaging systems through standard network (Ethernet) and standard communication protocols (TCP/IP) and/or DICOM upper layer protocol for TCP/IP.

Table 1: The summary of the preference ordering among the five interface models

Models parameters	sequential chain	direct interface	memory access	shared disk	interconnected network
cost	Very high	Low / High ¹	High	High ²	Low
rate of data transfer	Slow	Fast	Fast	Very fast ³	Medium
ease of implementation	Difficult	Easy	Easy	Easy ⁴	Easy
system portability	No	Yes	No	No / Yes ⁴	Yes

Notes: 1. The DR11-W is an in-expensive interface byt the DASM is a relative high cost interface.

2. The IDNET-2 is an expensive interface configuration.
The NFS configuration is not applicable.

3. If the PC is used as the PACS acquisition computer, no data transfer is required.
If the PC is one of the interface components, the image data need to be transferred to a PACS acquisition computer through Ethernet. In this case, the data transfer rate is between slow and medium.

4. The IDNET-2 is only portable within certain GEMS imaging systems.
The NFS method is portable if the imaging system possesses the NFS configuration.

An HL7 Parser for HIS/RIS Communication for the Medical Image Access System for Intensive Care Units (MIAS/ICU)

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1 INTRODUCTION

The Medical Image Access System for Intensive Care Units (MIAS/ICU) is a modular system which provides digital display of X-ray examinations in ICU environments remote from the department of Radiology. MIAS/ICU has been operational in one ICU of University Medical Center (Tucson, AZ) since mid-August of 1993. Due to a strong demand from the clinicians the hospital administration funded the acquisition of a display workstation to bring a second ICU on-line in December of 1993. The system automatically captures all Computed Radiography (CR) images generated by hospital's AC2 and FCR-9000 CR systems (Fuji Medical Systems U.S.A., Stamford, CN). Acquisition of these images requires no additional effort by the technologist. The images are captured at full resolution (approximately 2048x2048 pixels by 10-bits per pixel) and subsampled to a resolution of 1024x1024 pixels by 8-bits. Psycho-physical studies had previously determined that this resolution was adequate for the *clinical review* tasks in the ICU [KRU94]. Diagnosis and reporting is still performed by the Radiologist based on the film. All films remain in the department and are not available in the ICU. The acquired images are stored in a magnetic disk based short-term image archive operating on a DEC 3000/500 AXP running the OSF-1 operating system (Digital Equipment Corporation, Maynard, MA). Long-term archiving remains film based.

In the ICU image display is provided by a standard DEC 3000/400 AXP workstation configured with dual 1280x1024 color trinitron display monitors. The workstation operates using the OSF-1 operating system and runs an X-Windows/Motif based application which provides a very easy to use interface. The application interface requires no training for the end-users. Once a patient is selected the interface automatically displays the two most recent images available. The workstation provides local disk storage for caching of recently accessed images. Display of two images from local disk takes place in approximately one second. Display of two images from the image server, across the network, takes place in approximately two seconds. MIAS/ICU is interconnected using a 100 Mbps FDDI network.

The final component of the MIAS/ICU is the database server which maintains a relational database of patient information. This database operates on a DECstation

5000/240 running the ULTRIX operating system. This system supports two processes which work together to maintain a database of all the patients in the hospital, and service requests from the display workstations and the image archive. This system also acts as a translator, receiving HL7 format messages from the hospital network and converting it into format appropriate to update the MIAS database [SIM92, SID90]. This translation function is performed by the HL7 parser, called *Merlin* (after Medical Record Listener).

2 HL7

The HL7 standard specifies the static coding of information flowing between individual medical information applications [ROB90]. The approach used in HL7 is to define the format of the data sets exchanged between medical information and the sequences of data sets which comprise meaningful transfers of information. HL7 is an application standard and is not concerned with lower level communication protocols, or how the exchange of data is accomplished.

3 THE HL7 PARSER

The HL7 parser/translator provides a gateway for Admissions, Discharge and Transfer (ADT) information to pass from the Hospital Information System (HIS) network into the MIAS database. In addition to the high level (application) translation function, each side of the gateway is connected to a different type of physical networks and uses different network protocols. The protocol stacks and their relationship to the HL7 parser/translator is illustrated in Figure 3.1 below.

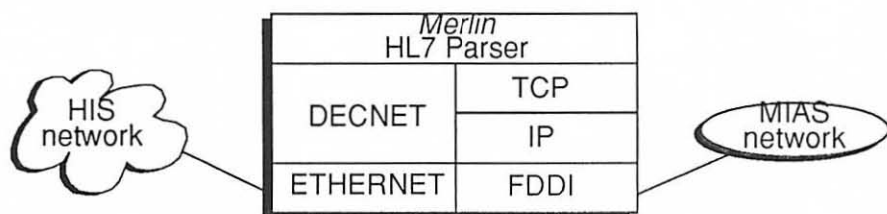


Figure 3.1 Protocol Stacks

Except for low-level handshaking built into the network protocol, all information flow is one way from the HIS network into the MIAS. This information flow is based on ADT broadcast messages and requires no queries from the MIAS. The information flow is illustrated in Figure 3.2 below.

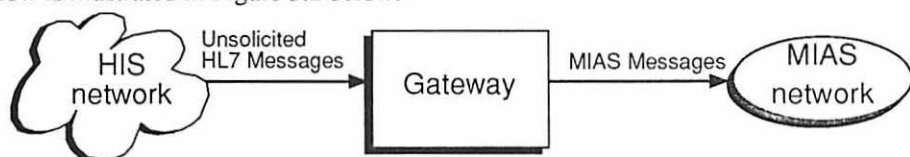


Figure 3.2 Information Flow

3.1 Architecture

The HL7 Parser running on the gateway resides on top of standard reliable transport mechanisms, as illustrated in the Figure 3.1 above, and is written in the standard 'C' programming techniques. The components of the parser consist of the following:

1. **Medical Record Listener**

This component is a DECnet object which receives the unsolicited HL7 messages from the HIS network. These messages are targeted to the appropriate DECnet object number. The listener passes the message to the parser/translator.

2. **HL7 Parser**

This component processes an HL7 message using the following functions:

a. **FILTER**

This function discards irrelevant messages based on a table of filter criterion which is dynamically accessed for each message.

b. **PARSER**

This function extracts specific data fields from the HL7 message.

c. **TRANSLATOR**

This function maps fields from the HL7 message into MIAS event messages.

3. **MIAS Interface**

This component uses the TCP/IP protocol stack to send MIAS event messages to the data server.

3.2 Implementation

The relationship of these components is shown in Figure below. The design follows a modular, open standards based approach. This approach enables reuse of components and easy adaptation to other HIS and RIS data sources.

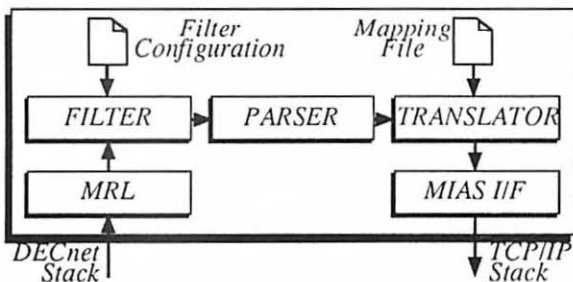


Figure 3.3 Relationship of Merlin Software Components

The use of configuration and mapping files allow definitions of the structure of HL7 messages, the specification of which HL7 messages are of interest, and how the message fields should be mapped into the internal MIAS/ICU message format. These files are checked each time a message is processed. This allows *Merlin* to be dynamically reconfigured without recompilation of the software. The files are simply edited with a standard text editor and the processing of the next message will reflect the modifications. This allows a great deal of flexibility, reuse of code for other protocols and allows *Merlin* to adapt to institution specific HL7 segments.

4 CONCLUSION AND FUTURE WORK

The MIAS/ICU provides fast access to chest images for clinical review in the intensive care units. Related information necessary for constructing the appropriate patient census and managing the database of patients and images is acquired from the HIS/RIS using the facilities of *Merlin*. The design approach used for this information gateway has proven to be very flexible and robust.

As the University Medical Center implements its current modernization program the existing DECnet based broadcasts will be modified to use TCP/IP protocols and a client/server architecture. HIS/RIS information will originate from a Datagate server and the MRL portion of *Merlin* will be converted to be a client. The modular architecture of this software will make this a simple process.

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SESSION 8

Expert Systems

Chair: Atsuko Heshiki

Computer-Aided Breast Cancer Prediction: Integration of a Mammography Findings Database with an Artificial Neural Network

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I. Introduction

Breast cancer is a serious health problem with an estimated 182,000 new cases diagnosed in the US this year. An estimated 46,000 women will die from this disease in 1993¹. Early diagnosis can significantly improve the long-term outcome for patients with breast cancer. Mammography remains the most sensitive technique for early breast cancer detection. Patients with mammographic findings which indicate a moderate to high probability of malignancy are sent to biopsy for confirmation. While mammography is a sensitive test, a significant fraction (70%) of those patients referred to biopsy do not have a malignancy. While specific, biopsy is an invasive, costly, and emotionally stressful procedure. In an effort to improve the accuracy and consistency of diagnosis, an artificial neural network (ANN) technique is being developed to predict the outcome of biopsy (benign/malignant) from radiographic findings and medical history. This ANN provides an accurate prediction of malignancy as an additional diagnostic finding for the physician to consider when forming a diagnosis.

The full development of such a system provides three significant improvements for early breast cancer detection: 1)increase the diagnostic accuracy of mammography for predicting malignancy of breast masses; 2)decrease the number of patients sent to biopsy with benign lesions (and thus provide a significant savings of healthcare costs); and 3)increase the consistency of diagnosis for mammography. This last improvement will be a result of the development of a computer algorithm since it has no intra-observer variability.

The implementation of an on-line reporting system for mammography has provided an ideal environment for developing this system. With the ANN connected to the reporting database, the network can be trained and evaluated as new cases are presented.

II Methods

An ANN for malignancy prediction was implemented as a two layer backpropagation architecture. Input feature values were the radiographic findings assigned by the radiologists. The output was a number between 0 and 1. Output values near 1 indicate that the outcome of biopsy will be malignant. The ANN was trained by giving it a large number of examples of inputs (mammographic findings) along with the true outcomes (results of biopsy). Internal numerical weights were adjusted to minimize the mean squared error between the network output and the known outcome from biopsy. The ANN training procedure results in a network which can generalize from new input data (which it has not seen before) to make an intelligent guess at the outcome. Once trained, the network should predict the biopsy results when presented with the mammographic findings as input. The strength of this approach is that the ANN "learns" the relationship between findings and outcome based on many examples.

A two-layered backpropagation neural network was created for training and testing with the mammography data. The input layer consisted of 8 nodes which represented the eight categories of radiographic findings (excluding the overall radiological impression). For the preliminary study, a paper checklist was used to acquire the input data. The features include: 1)mass size, 2)mass margin, 3)density asymmetry, 4)architectural distortion, 6)calcification number, 6)calcification morphology, 7)calcification density, 8)calcification distribution. The radiographic information was scaled and presented to the network as numerical values. In addition, the checklist also contained an overall radiological impression assigned by the radiologist. This impression was scaled such that 1=benign; 2=probably benign; 3=indeterminate; 4=probably malignant; 5=malignant. The hidden layer consisted of 12 nodes. The output layer consisted of a single node representing diagnostic outcome. For the training cases, the output node was set to zero if the biopsy pathology was benign and to 1.0 if the result was malignant.

The checklist-style findings entry form has been recently replaced with a workstation with a graphical user interface. The findings are now entered directly into a database using this workstation. In addition, medical history and biopsy outcomes are also available through the database. This database is ideal for the development of a computer aided diagnosis system.

In the preliminary experiment, the network was trained on 153 cases (50 malignant and 103 benign) chosen randomly from the 203 cases which had been followed up by surgical biopsy. The training was "supervised"; for each training case the network was provided with both the input of radiographic findings and the corresponding biopsy diagnosis (0.0 if the biopsy pathology was benign, 1.0 if malignant). The remaining 50 cases (38 benign by biopsy, 12 malignant) were used as the testing set. When presented with this testing set, the network provided an output between 0.0 and 1.0 predicting the probability for malignancy. The predictions of the radiologists and the network were compared using receiver operating characteristic (ROC) analysis. Differences in performance were evaluated by comparing the areas under the ROC curves (A_z).

III Results

The ROC results for the 50 test cases are shown below. An important feature of the ANN performance can be seen by examining the true positive fraction for the ANN. In this study, the decision threshold could be set to increase the specificity to 60% while maintaining 100% sensitivity. The specificity for the radiologists was 5% for 100% sensitivity.

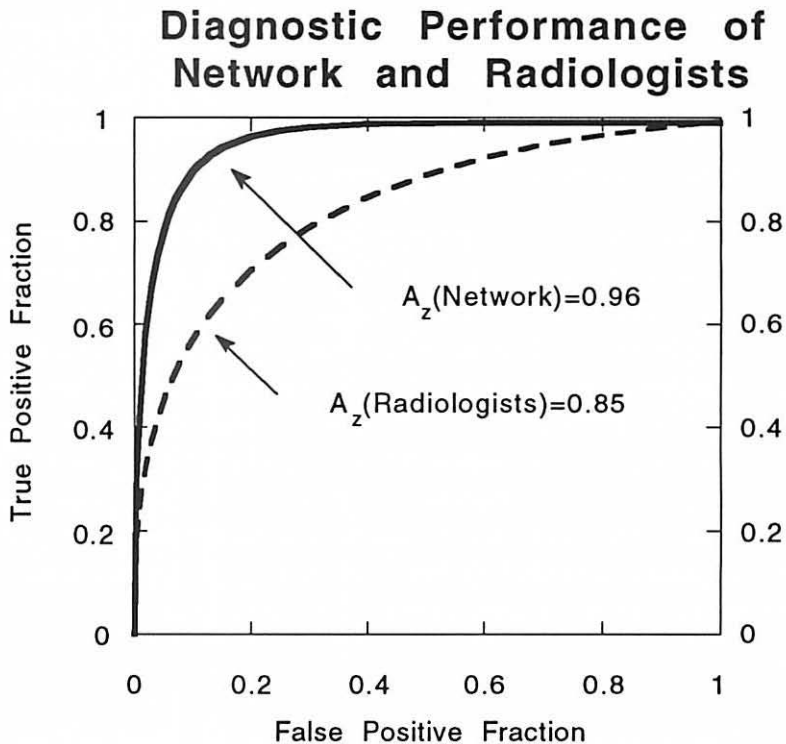


Fig. 1 ROC comparison of network and radiologists for the entire testing set.

The radiologists' estimate of probability for malignancy determines the recommendation of biopsy for a patient. To use the results from a neural network, a decision threshold must be set. If a threshold were set at 0.7, the network would have sent all of the malignant cases to biopsy but would only have sent 8 of the 38 benign cases (Sensitivity = 1.0, Specificity = 0.79).

IV Discussion

An ANN was developed to predict breast cancer from mammographic findings. Radiologists read the mammograms and filled out a list of eight findings. These findings were encoded as features for an ANN. Results from biopsy were taken as truth for the diagnosis of malignancy. The ANN performed more accurately than the radiologists. ROC curves comparing the performance of the trained network with the radiologists showed a significant difference in the performance of the ANN compared with the radiologists. The area indices (A_z)

are 0.96 for the ANN and 0.85 for the radiologists. A_z for the ANN is significantly better with a p -value <0.05 . These results indicate that an ANN can be trained to distinguish malignancy with a high degree of accuracy in cases which are currently read as indeterminate, possibly suggesting a technique for reducing the number of benign biopsies.

Several computer aides for extracting features from mammograms have been investigated previously. A computer aided technique for detecting breast masses has been described with the conclusion that while promising, the system alone was not reliable enough for diagnosis².

Automated systems for detecting clustered microcalcifications³ and masses⁴ have been described. From this work, a real-time CAD system was demonstrated at RSNA in 1992⁵ for computer aided identification of masses and clustered microcalcifications with a sensitivity of 0.85 and a false positive rate of 1.5 to 3 per image.

Computer aides for breast cancer *diagnosis* have been presented as either discriminant function analysis⁶, expert systems⁷, or ANNs⁸. Radiographic features have been used as inputs in a discriminant function analysis where the CAD system improved specificity at the cost of decreased sensitivity⁶. A preliminary report of an expert system for predicting malignancy of calcifications⁷ quoted an accuracy of 73% for cases which radiologists had referred to biopsy.

The significant difference between previous work and the work described here is the coupling of an ANN with a reporting database to allow continual update and evaluation of the network on new cases.

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A Conceptual-Graph Framework for Structured Reporting in Radiology: Application in Pelvic Ultrasound and Breast Imaging

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Introduction

Although patient records are increasingly computer-based, radiological reports typically are stored as "free" narrative text. Without widely available natural language processing, it is difficult to reuse this narrative data for automated decision support, for clinical research, or even for automatic summarization of an individual patient's course. An alternative to narrative text is provided by "structured data entry," in which clinicians enter observations by selecting concepts directly from a controlled vocabulary.

There is a long history of work on structured data entry in radiology [1-4]. More recent efforts have been directed at taking full advantage of graphical user interfaces [5-7], leveraging the contribution of nonmedical personnel [6], and utilizing deeper models of the domain of discourse [5,8]. Despite these efforts, no system has yet proved generalizable. One obstacle to generalizing structured reporting systems is the difficulty of sharing vocabularies and concept models.

We have developed a methodology that utilizes the conceptual graph formalism to organize concept models for structured reporting [9]. We have applied this technique to formulate concept models that incorporate the main findings used in pelvic ultrasound and breast imaging reports. In addition, we have developed of a software system that directly utilizes conceptual graphs in presenting forms for structured data entry.

Conceptual Graphs

Conceptual graphs consist of concepts and their relations to other concepts [10,11]. Concepts may be linked to more general concepts; for example, a [Right Breast] is a [Breast], which in turn is a [Paired Body Part]. A concept's properties are expressed by its relations to other concepts; these properties are inherited implicitly by its more specific sub-concepts. In the example above, one can write:

[Paired Body Part] -> (has laterality) -> [Laterality].

[Right Breast] -> (has laterality) -> [Right].

Existing controlled vocabularies, such as the National Library of Medicine's Unified Medical Language System (UMLS) [12], the American College of Radiology's (ACR) Index for Radiological Diagnoses [13], and the College of American Pathologists' Systematized Nomenclature of Medicine (SNOMED) [14] can index radiological reports for retrieval, but typically lack sufficient detail to represent a report's primary content [15].

Methods

The authors developed conceptual-graph models for reporting pelvic ultrasound and breast imaging findings using the controlled vocabularies of the UltraSTAR structured data entry system [6] and the ACR's Breast Imaging Reporting and Data System (BIRADS) [16]. Software tools for manipulating conceptual graphs and for automatically laying out user-interface forms for report construction have been built in Macintosh Common Lisp 2.0 using the Common Lisp Object System (CLOS). Testing the original concept models with our software tools provided a basis for modification of the models. This testing also revealed additional software needs and stimulated modifications of our software tools.

Results

Software tools. The Model-Based Structured Reporting Toolkit currently consists of three modules. Each module in turn consists of a set of CLOS classes and associated functions. The Model Server module manages a semantic network of concept types and relations. The

Conceptual Graph Parser module converts ASCII conceptual graph syntax into an internal (object-oriented) format and integrates new conceptual graphs into the Model Server's semantic network. The Model Editor module provides an interface for browsing and editing a semantic network concept model. The Conceptual Graph Forms module generates user-interface forms for data entry from specifications that are represented by conceptual graphs. Together, the four modules contain 29 CLOS classes and 265 CLOS methods and Common Lisp functions.

Concept models. The ultrasound model consists of 103 concepts and 13 relations. The breast imaging model consists of 386 concepts and 23 relations. The broadest organizing concepts in both models are Finding, Anatomic Locus, Diagnostic Procedure, Attribute, Attribute Value, and Observation.

Conclusions

These experiments demonstrate that conceptual-graph models — which can represent concepts more deeply than existing controlled vocabularies — can form a basis for structured reporting. Use of these models for structured reporting can affect their design and content. Further work is needed to optimize the model development process, merge models from overlapping content domains, establish the clinical efficacy of model-based reporting, and find the best methods of retrieving model-based reports.

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The Utilization Trilogy: Three Software Programs That Focus on Utilization of Imaging

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During the past four years, three software programs have been developed with the goal of improving utilization of imaging resources through the mechanism of a structured, data-driven, decision-making process. The programs have similarities and differences related to their goals and how those goals are achieved. The purpose of this presentation is to briefly describe the programs and to highlight the similarities and differences so as to shed light on the design of software for improving utilization of imaging resources.

THE CLINICAL-EDUCATIONAL INTERFACE

The first in the series, the Clinical-Educational(CE) Interface was created in SuperCard to give a visual view of the diagnostic and therapeutic course and to encourage a logical evaluation of that course and its individual events. Just like a history and physical, the CE Interface makes the student answer questions that are relevant to the situation, an approach termed "event analysis." The CE Interface is composed of two screens. One is a graphical representation of the patient's diagnostic course. The other is a more detailed representation of each event.

The key element in the CE Interface is the event card, the focus of which is a rectangle entitled with the event to be considered. Buttons on the rectangle link to fields residing on another cards. These fields are also titled and are "the questions" which the students must ask about the event. For example, on a computed tomography event card, pressing the button labeled "images" links to a card that has pertinent images on it. The "report" button links to the descriptive, text-based report about those images. There are categories of buttons. The "reports" and "images" buttons link to information that is patient-specific. The "cost," "availability," and "preparation" buttons are event-specific. That is, they contain information specifically about the CT examination. The information does not necessarily effect the evaluation of the disease findings, but is important in the decision-making process that occurs in the diagnostic course at that event. Other buttons link to functions or tools that may aid the physician in evaluating or learning from the particular event. The "literature" button accesses information sources,

such as Medline, and serves as a place to put that information. "AI" links to expert systems, decision-making programs, and other tools in which the event and course information may be placed and evaluated. Finally, some of the buttons link to fields where the student must assimilate information and make conclusions. In the "appropriateness" field, indications for obtaining the CT in the patient must be evaluated. This is a prospective evaluation that requires knowledge of the previous course, as well as knowledge about CT, such as its availability at the institution, its cost, the risk that it entails, and its effectiveness in comparison with other imaging modalities. Information from these other fields may be brought to the "appropriateness" card. The student then composes his response.

The information environment in which such a card might be used is extremely variable. It may be necessary for the user to obtain information from paper-based systems and type in the data. Automated information systems may be available which allow the information to be electronically transferred from the system into the CE Interface. In the latter situation, the user may either cut and paste information or they may click on a button which has embedded within it the standard query that is performed using the information relevant to the event. For example, clicking on the "cost" button initiates a query compiled by obtaining the title of the card, "CT," and going to the "study info" card, which might say whether or not contrast was used. The images query would obtain the information, patient name, date, and exam type, and would access the designated CT.

The diagnostic and therapeutic course template is designed to give a overall view of the patient's time-related evaluation and treatment. The template is comprised of event cards in a matrix configuration. The event cards are visually linkable and are color-coded for a information source. The rows define the time course of the events. All of the event cards for a particular information source have the same structure. All of the imaging cards have the following fields: images, report, cost, study info, risk, appropriateness, preparation, availability, literature, AI tools, value, and quality assurance. Some of the fields, such as "imaging," are completely different than those in other information sources. Some of the fields have the same title and general structure but access databases that are particular to that column. The "cost" database for imaging would be different than that for surgery. Other fields are essentially equal; literature, AI tools, etc. would behave and be used similarly across the sources.

A retrospective analysis is performed. The clinician relates the actual information acquired by the examination to preliminary expectations, risk, cost, etc. If any risks were realized, then they are evaluated. If availability differed from the norm, it is described. The fields "value" and "QA" are provided for the analysis. Evaluation then leads into a determination of subsequent information needs and possible avenues to fulfill the needs.

The advantages of the CE Interface include its simple, graphical representation of the diagnostic course and its focus on event analysis. Linked to a network, it provides access to information resources. It provides a rational structure for evaluating and making decisions about an event. The two screens provide a functional focus for group discussions about clinical situations.

On the other hand, filling in the categories and boxes required a moderate amount of effort and considerable time in a busy clinical schedule. To do this for each event in a patient's diagnostic course would be dysfunctional. It is more applicable to occasional case discussions and presentations and not to direct clinical use. While emphasizing accessing information from a variety of sources over a network, it was never completely implemented within the network.

WAYS AND MEANS

Ways and Means is intended for both clinical and educational use. A consultation tool as support for the radiologist or as a direct reference for the clinician, it is designed for the rapid access of specific bits of information that are of common clinical significance. Ways and Means focuses on information useful to making decisions about the utilization of imaging resources.

In the educational mode, Ways and Means provides a highly structured presentation of information on clinical topics. Initially created in an outline, each module limits the amount of text, relying more on the structure and design than on grammar to make it readable. All of the information, including a background section, is related to imaging. A student, resident, or clinician learns how and why various modalities are used in the diagnostic evaluation of clinical situations.

Ways and Means was developed concurrently with the CE Interface. It borrows much of the CE Interface's event analysis approach, but specifies it for imaging and adds other features for imaging. The information in Ways and Means can be applied to a single event in the diagnostic course, but it focuses on the imaging work-up of entities. It compares modalities that could be used for a clinical problem and addresses the sequence in which the modalities might be used. To date, Ways and Means has been applied to emergency medicine clinical situations, where very goal-directed information is sought by clinicians. Emergency physicians need specific bits of information, which they can quickly apply to the situation at hand. They do not have the time necessary to work with a program such as the CE Interface, which is more process oriented.

Ways and Means was initially developed using only HyperCard, a program that is card-based and hypertext-oriented. HyperCard has a search function that is good for finding specific bits of information, a feature that matches the way Emergency physicians work and seek information. An inexpensive and commonly

available program, Hypercard is graphically-oriented and easy to use. On the other hand, HyperCard requires that individual stacks be created for each entity module. To alleviate this problem, a background database, HyBase[®], was incorporated into Rays and Means, resulting in easier data entry, improved function, decreased stack size, and greater capacity. Rays and Means has been designed so that relatively few clicks are needed to access any part of the application. To further simplify navigation, a map can be used to go directly to a card. Each module addresses one topic, such as renal trauma. Topics are listed on the initial stack card and are loaded by clicking on the term. At this time approximately thirty topics have been researched and created and four topics entered into modules.

Each module has two parts, background information and imaging modalities. The background information section is highly structured section with emphasis on topic information that is pertinent to imaging. The section includes the headings, "Introduction," "Classification," and "Clinical Status," of the outline. Under each heading is information that impinges upon the choice of imaging modality, the imaging possibilities for the topic, the associated clinical information, and information that serves to focus the role of imaging in the diagnostic work-up. Most people access background information as part of an educational process. However, information about sensitivity and specificity of history, physical examination, and other tests and examinations is stored here and may impinge upon the ordering of a imaging examination or the interpretation of that examination in the clinical environment.

The heart of the application, the imaging modality section, yields information about a variety of factors, such as cost, availability, risk, and preparation. Statistical information regarding the potential impact of an imaging exam is presented as is statistical information about the results of the exam. For the former, statistics focus on the possibility of a particular test yielding relevant information for a particular situation. For the latter, the statistics are associated with the examination findings and how those findings relate to the determination of a diagnosis. In our experience, statistics from one article are not easily compared with statistics from another. Therefore, they are grouped and listed as logically as possible.

In the imaging modality section, images are placed that illustrate the modality as it used for the current situation. A variety of functions are available to deal with the images. The users can seek images that demonstrate specific findings. They can find statistical information associated with specific findings. They can list cases that they have had at their institution that demonstrate the findings or have been used to evaluate the clinical entity. Thus, Rays and Means can be a utilization management tool for data collection. The program also provides an easy way to label and place arrows on images, which can be shown with and without arrows

SCORECARD

Whereas Rays and Means seemed to fit best in a consultative mode for major imaging examinations, ScoreCard is an attempt to impact on the majority of utilization decisions. For a clinician to use Rays and Means, they would access a particular module, such as right upper quadrant pain, and seek specific information. It is very much a reference and separate from standard process or routine in the emergency department. ScoreCard was developed to tie utilization of imaging to a common clinical practice, order entry. By linking the features of the CE Interface and Rays and Means to physician order entry, we want to make consideration of imaging utilization both functional and unavoidable.

At this point, ScoreCard has been developed to Phase I in FoxPro, a programmable database. It is designed in several layers. Phase I is comprised of exam selection, demographic information entry, and definition of the indication. For a selected examination, the clinical information includes the reason for the radiographic study, a listing of clinical findings, and definition of selected points from the physical examination. Data entry occurs via check boxes.

Our initial examination was plain film evaluation of the spine. Under "Reasons for radiographic study" are listed motor vehicle accident, fall, assault, medical legal, obtained because of protocol, and other. Motor vehicle accident is further delimited by selecting whether or not a patient was restrained, unrestrained, ejected, traveling at least than 30 miles per hour, traveling greater than 30 miles per hour, or a pedestrian. For falls, a height of greater than or less than 10 feet can be selected. Clinical findings include whether or not the patient is a reliable historian, the reasons for unreliability or unobtainable history, the presence of significant head trauma, an indication of whether or not other significant injuries were present. A simple listing of the history and physical includes presence or absence of pain, tenderness, and an abnormal neuro exam.

The intent of Phase I is essentially to provide the clinician with a list of acceptable indications for an examination. The ordering physician can assume that an examination is reasonable if the indication is found in ScoreCard. If "other" becomes the indication, then the physician should consult the radiologist about the appropriateness of the examination. The vast majority of clinical situations will not require direct physician consultation. Only those that are truly questionable will be the subject of a consult.

In future phases additional information will be made available to the clinician during the order entry process. This information will be divided into requestable and unrequested information. In the latter might be the cost of the procedure. This can be easily obtained and displayed at the end of the order entry process by accessing cost schedules. On the other hand, requestable information

would be that which requires some time and effort to either acquire or to assimilate. This would include information about examination sensitivity and specificity for a particular indication. It might also include information about availability or preparation, about which the physician can make a decision regarding the relevance in the particular situation.

Our goal is to structure ScoreCard so that information about the ordering physician's utilization can be fed back to the physician during the ordering process. For example the physician who orders short term follow up chest radiographs on patients with pneumonia who are afebrile may find that their yield is quite low. The yield could be related to other physicians in the department. In either case the information would be presented at the time of ordering for the physician to evaluate. It could be requestable or, if the statistics are far out of line with other physicians, could be made unavoidable.

The primary advantage of ScoreCard with regard to utilization is that it is being tied to physician order entry, a point of decision making. Impact upon utilization is best made at the time a decision is made and when the decision maker, usually the clinician, has authority to make the decision.¹ Just having information about cost can decrease utilization.¹ In contrast to the approach of a simple database with ICD-9 and CPT codes and limited judgment fields, ScoreCard gives clinicians more usable information from which to make a decision about their utilization patterns. Since it allows the clinician to evaluate the data and come to a conclusion, ScoreCard is potentially much less public and punitive. Finally, it provides a database mechanism for collecting data that can be used to evaluate specific indications for imaging procedures.

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A Computer System for Providing Feedback to Physicians to Influence Their Ordering Practices

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SUMMARY

In recent years there has been a constant public and governmental pressure to reduce health care cost while providing high quality care to patients. This can only be accomplished by appropriate utilization of resources, and by eliminating procedures that have a low yield in terms of patient management. Also, in order to provide optimal care, patients need to be tracked to ensure that they are receiving the appropriate screening procedures such as mammography.

This paper describes a computer system that analyses data and provides feedback to physicians in order to influence their ordering practices and encourage them to adhere to established guidelines, assist in providing appropriate care, and reduce cost. This system is designed as an automated electronic patient record with the ability to track any type of data. Tracking can be instituted at multiple levels. The initial system and some of its applications were described at CAR'93¹.

The system has been upgraded and a new application added which provides data on physician ordering practices by individual procedures in the Radiology Department (and other departments), and by volume generated by individual physicians. The average cost per DRG (Diagnostic Related Group) is calculated, and feedback on the ordering practice, and the resultant cost, by individual member, is provided to each department. The department and each member can then review the data and establish guidelines for the appropriate procedures necessary for the optimum care of a patient for each DRG. The extent to which these guidelines are being followed can be tracked

and the information disseminated to the department and the individual physicians. Both over-utilization and under-utilization of the established guidelines can be determined.

System capabilities

The system is designed as an automated electronic medical record, in a managed care setting, for inpatients and outpatients, with the ability to track any type of data. The hardware consists of Data General Minicomputer Distributed Processing System consisting of sixteen(16) DG S-280 minicomputers, 500 terminals, 100 printers and four(4) Gigabytes of main storage. The system operates on the RDOS/CHAMPS operating system, with applications written in Hybrid "Basic/Assembly" language with random access file structure.

The member base in the service area is 185,000. These members are seen in a 243 bed hospital with a medical office and seven other outlying clinics which is supported by 392 physicians and over 50 non-physician practitioners consisting of physician assistants and nurse practitioners. The Imaging Department performs 338 different imaging procedures totaling over 160,000 examinations per year. The system is capable of tracking all the orders generated by the physician and non-physician practitioners to the Imaging Department and to all other departments. It is, therefore, capable of calculating the cost of a DRG, and providing feedback on the ordering practices of the individual practitioners. An example of the ordering practice of a particular department, e.g., the Internal Medicine Department is given below.

Ordering practice of members of the Internal Medicine Department

The Department of Internal Medicine has 37 physicians. In the interest of saving space, ten members of the Department and five of the 388 Imaging procedures have been randomly selected in Table 1 to demonstrate the type of information available on physician ordering practice. This data covers inpatients only, but the same type of data can be generated for outpatients as well. As previously reported¹, the function of the computer is very general, and it can provide feedback

on the ordering practice of any number of practitioners on any number of procedures performed in Imaging or in any other department within the service area.

Patient-days in Table 1 is proportional to the number of patients admitted to the hospital by an individual physician, and the severity of the illness. The number of patients and the severity of their illness is known but not indicated in Table 1. The information covers a period of one year. The number of studies shown may be smaller compared to other hospitals since most of the work-up in our setting is performed on an outpatient basis.

TABLE # 1

PHYSICIAN	CHEST UC \$11	BE UC \$65	V/Q SCAN UC \$160	CTABD UC \$320	MRI BRN UC \$436	PATIENT DAYS
1	60	6	1	9	5	707
2	86	2	1	2	2	758
3	47	0	3	26	1	762
4	90	0	4	21	1	1021
5	89	0	6	19	9	858
6	143	2	7	25	3	1422
7	123	2	10	8	2	1187
8	127	1	5	13	3	715
9	59	1	4	20	4	998
10	32	2	3	9	0	474
Average	86	2	4	15	3	890

Ordering practice of ten physicians in Internal Medicine.

Each physician receives a report showing his/her practice pattern compared to the department average in numeric and graphical form. As an example, the practice pattern per comparable patient days is shown in numerical form in Table 2, and in graphical form in Figure 1. The data is the same as that in Table 1. A summary of the practice pattern of each physician is sent to the Chief of the department. It is left up to the members of the department to evaluate whether the high or low utilization of a service by an individual physician was appropriate, and if not, then to provide guidance regarding appropriate utilization.

TABLE #2

PHYSICIAN	CHEST /100 PD	BE /1000 PD	V/Q SCAN /1000 PD	CTABD /100 PD	MRI BRN /1000 PD	PATIENT DAYS
1	8.5	8.5	1.4	1.3	7.1	707
2	11.3	2.6	1.3	0.3	2.6	758
3	6.2	0	3.9	3.4	1.3	762
4	8.8	0	3.9	2.1	1.0	1021
5	10.4	0	7.0	2.2	10.5	858
6	10.1	1.4	4.9	1.8	2.2	1422
7	10.4	1.7	8.4	0.7	1.7	1187
8	17.7	1.4	7.0	1.8	4.2	715
9	5.9	1.0	4.0	2.0	4.0	998
10	6.7	4.2	6.3	1.9	0	474
Average	9.7	2.1	4.8	1.8	3.5	890

Practice pattern per comparable patient days.

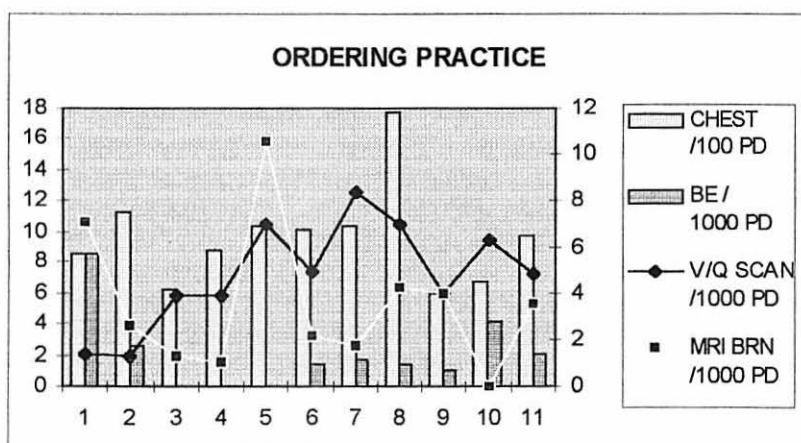


Figure 1: Ordering practice in graphical format.

Results of feedback to physicians

The provider costing analysis program has been in effect for approximately one year. Initial data shows that it is effective in reducing cost, and in helping physicians adhere to practice guidelines. An example is shown in Table 3 which compares the average length of stay (ALOS), laboratory cost per case, x-ray cost per case, and total

cost per case for DRG 209 (major joint and limb reattachment procedures-lower extremity) in the department of Orthopedics, for the period Jan 93 through June 93, and July 93 through December 93. There are other costs in the report that are not shown here. The data shows that feedback to the physicians reduced the overall cost for DRG 209.

TABLE 3

Period	Number of cases	ALOS days	Lab cost /case in \$	X-ray cost /case in \$	Total cost /case in \$
Jan93-Jun93	74	7.4	213	15	277
Jul93-Dec93	48	6.1	186	17	223

Effect of feedback to physicians on cost.

Monitoring of Practice Guidelines

The Imaging Department performs over 17,000 screening and diagnostic mammography examinations per year. Prior to July 1993, asymptomatic women between the ages of 40 and 50 were encouraged to have a baseline mammography examination at age 40, with follow-up examinations every two year, as recommended by the American Cancer Society and other national medical specialty societies. Investigations over the past 20 years by eight different international groups have shown limited benefit from mammography in the 40-50 year age group, in terms of survival, but significant benefit in the 50-74 year age group. Practice guidelines were, therefore, developed to ensure that the 50-74 year age group was screened every two year, and the physician and non-physician practitioners in the group were educated on the new criteria in July 93. This computer system allows the ordering practice of an individual practitioner to be monitored, and the information is then fed back to the individual on a periodic basis to assist that person adhere to the guidelines. The data is distributed to each practitioner and to the Chief of service for review. Table 4 shows two 9-month sets of data that represents a 20% sample size. The data shows that the feedback was effective in

increasing the number of mammograms in the 50-74 year age group, and in reducing the procedure in the lower age group.

TABLE 4

Period	Number cases	< Age 40	Age 40-50	> Age 50
Sep92 - Jun93	1548	9%	29%	60%
Jul93 - Mar94	2006	6%	26%	66%

Effect of feedback to physicians on practice guidelines.

Conclusion

Preliminary results obtained from the system shows that physician ordering practices can be influenced by feedback. It has the potential to reduce cost by appropriate utilization of resources without compromising patient care.

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SESSION 9

MDIS

Chair: Quinn H. Becker

U.S. Military Medicine: PACS, Telemedicine & Personal Digital Assistant Devices

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The U.S. Military through the Medical Diagnostic Imaging Support (MDIS) System and the Telemedicine (T-Med) Project are accessing, testing, and deploying various technologies for military medicine. MDIS and T-Med are actively involved in large scale Picture Archival and Communications Systems (PACS), teleradiology, telemedicine, speech recognition for dictation of medical reports, and personal digital devices for physicians on the wards and in the clinics. MDIS and T-Med are Military Tri-Service projects run out of a project management office on Fort Detrick in Frederick, Maryland. The project management office is compiled of a composite team of physicians (Emergency Medicine and Radiology), physicists, engineers, hospital administrators, technologists, and specialists in computer systems, communications, and logistics. End users of the technology (usually physicians) at clinical sites drive the development of the various programs. In general, a rapid prototyping approach is utilized. This approach is indicated in advanced development situations where more traditional research and development approaches are not able to keep pace with the tempo of rapidly evolving technology such as high bandwidth telecommunications and digital imaging. Under the rapid prototyping approach, a technology must possess some immediate, practical, operational value in its deployment, and in addition possess elements that "push the envelope" to rapidly assess both new technology and new operating concepts.

In this presentation, three projects under the MDIS/T-Med umbrella will be briefly reviewed: 1] MDIS PACS, 2] Operation Primetime (telemedicine for Macedonia and Croatia), and 3] ProjectProMED (a personal digital assistant device for physicians on the wards and clinics).

MDIS PACS:

The MDIS PACS contract was awarded to a joint venture between Loral and Siemens in late 1991. Presently, Madigan Army Medical Center, Brooke Army Medical Center, and Wright-Patterson Air Force Medical Center are undergoing phased implementation of this system. Additional sites are planned for 1995. Madigan, which was the first site to begin clinical operations (March 1992) will be emphasized.

Madigan, a 416 bed hospital, is located in Tacoma, Washington. Four hundred physicians support more than one million outpatient visits per year. Nearly 160,000 radiological procedures were completed in 1993 in a radiology department staffed with 14 Board certified radiologists and 20 radiology residents.

PACS equipment at Madigan presently includes computed radiography (CR) for all plain radiographs except mammography, a 40 Gbyte Working Storage Unit (WSU), a 100 platter (1 Tbyte) Optical Disk Jukebox (ODJ), and 25 workstations. CR images are processed by 2 Siemens Digiscan 7000s and 3 Fuji AC1 plus readers. Third and fourth generation Fuji imaging plates with lead backing are used.

The heart of the MDIS system is the Working Storage Unit (WSU) which functions as the local and short-term storage device. Originally developed and utilized for U.S. military reconnaissance, but now modified for medical applications, the WSU uses a redundant array of inexpensive disks (RAID, level 2 architecture) with 40 disks operating in parallel; 32 disks for a 32 bit word, 7 disks for error correction, and one disk acting as a "hot spare" (single disk failure detected and corrected without loss of operation). Presently all images obtained within the last 10-12 days are available on the WSU. Images are stored in the WSU with approximately 2.5 : 1 lossless compression giving an effective storage of 80-90 Gbytes of data (greater than 10,000 CR images). Image retrieval bandwidth is greater than 400 CR image equivalents per minute. The WSU is connected to the workstations by a fiber optic network in a modified star topology.

Image data moves with FDDI-like speeds (100 Mbits/sec). Images are transferred at the earliest opportunity from the WSU to the ODJ. The ODJ holds 100 (10.2 Gbyte) 14" WORM optical disks. CR images are stored with 10:1 lossy compression (modified JPEG format). The final phase calls for two ODJs which will be able to store 4-5 years of images on line [1-2].

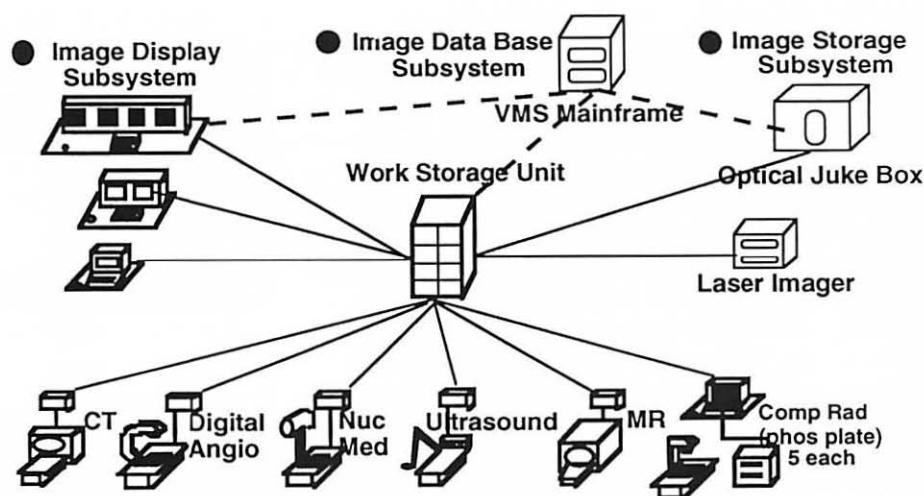


Figure 1 : The basic MDIS PACS configuration.

The system utilizes two types of imaging workstations, "diagnostic" and "clinical". The diagnostic workstation is a high volume unit for primary diagnosis; the clinical workstation is a lower volume unit for review of images. Diagnostic units can have either 2K (A type) or 1K (B type) resolution portrait monitors. Clinical units have only 1K (C type) resolution landscape monitors. In the radiology primary reading areas, diagnostic workstations use four 2K monitors. In general, the wards and clinics have two 1K clinical workstations, but the entire 2K data set is available by magnifying the image. All workstations have the same image manipulation functions. Presently there are 25 workstations throughout the hospital, but later in 1994 the number of workstations will increase to 116.

The Macintosh-based interface, being extremely user friendly, is one of the reasons for broad acceptance since many of our physicians are computer illiterate. Ease of initial training and retention of training are due to mouse-driven pull-down menus. "Quick keys" are available for the commonly used functions so an experienced user can move through the functions more rapidly.

Presently CR, CT, and Fluoroscopy are on the system with an integrated Radiology Information System (RIS). Many other image

modalities are expected to come on-line in 1994 including MRI, Aegis (Acuson) ultrasound miniPACS, Nuclear Medicine, Angiography, and CHCS (the Department of Defense's Hospital Information System) .

At Madigan, greater than 500,000 digital images are available on-line to physicians. The system reliability has been 96-99%, and image accountability on the PACS has been from 95-99% (with <0.6% truly lost images). Image display time from the WSU is 4-5 seconds. Clinician acceptance is high with greater than 98% stating that the PACS significantly improves patient care [2]. Emphasis in 1994 will be on converting the hospital into a truly filmless environment, connecting the remaining image modalities into the system, and integrating the PACS with our hospital information system.

Operation Primetime (Telemedicine):

Operation Primetime provides Telemedicine support to the 364 US soldiers remotely deployed in Macedonia as part of the overall United Nations (UN) deployment within the former Republic of Yugoslavia. Primetime also provides Telemedicine support for patients at the Air Transportable Hospital. The intent of the operation is to deploy, establish and operate the Primetime Telemedicine Network (Figure 2) for an extended period of time—anticipated to be at least 120 to 270 days.

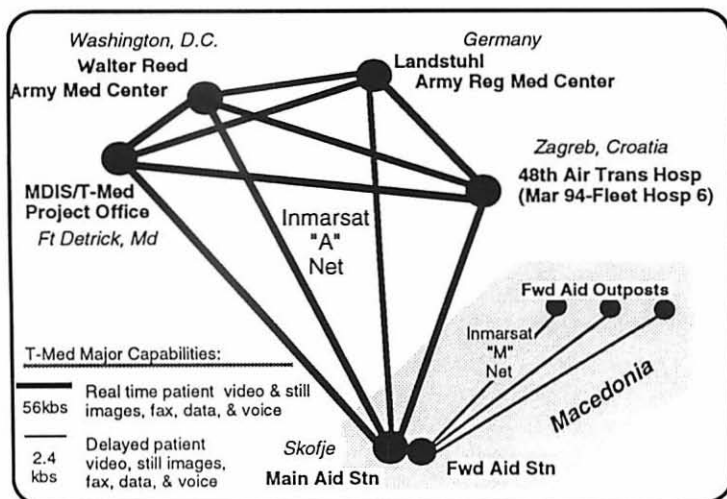


Figure 2:

Five major validation questions for operation of this telemedicine project are being evaluated:

1] Can a multi-node Telemedicine network be successfully designed, deployed, and operated in support of remote military medical operations. Can such a network be operated over an extended period of time with a high degree of uptime and technical reliability?

2] What are the clinical benefits and drawbacks of such a system based upon its actual use over an extended period and what are the economic benefits and costs in using deployed Telemedicine networks?

3] Does a multi-media approach to Telemedicine using real time patient video, high-resolution still imagery, as well as data, facsimile, and voice communications provide the expected operational usefulness? What technologies make sense for incorporation into a multimedia-based Telemedicine system? Can such a system be successfully integrated as an open system that stresses the major properties of inter-operability, scale ability, and upgrade ability over time?

4] Is it possible to establish an image-capable multi-media patient database for a contingency operation and have it serve as a "medical flight recorder" of the clinical activity of the operation for retrospective analysis and epidemiological medical research?

5] Is it possible to build a system of seamless medical support in which tertiary care expert military medical capability can be aggressively teleprojected into a remote medical setting through the use of Telemedicine techniques?

The enabling technologies are listed in figure 3.

<i>Enabling Technologies:</i>	<i>Purpose:</i>
● Inmarsat "A"	Patient video, fast still image, data, fax, voice transmission
● Inmarsat "M"	Voice & low data rate comm
● 56kbs SynchRouter	Asyno to syno data conversion
● Low Data Rate Video Conference Units	Patient video in real time
● Kodak DCS 200 & Canon RC570 Direct DigitalCamera	High resolution still imagery
● Patient Digital Device Pkg-Digital Otoscope, endoscope, derm scope, & auscultation devices	Acquisition of patient physiological assessment imagery & data
● X-ray High resolution digitizer	Diag quality x-ray images
● Hi 8mm Video Cam Corder	High resolution video acquisition
● Mac Powerbook 270C/180C	Portable PC platform
● Mac 840AV Workstation	Image capable multimedia workstation platform
● Personal Digital Assistant	Productivity assistant for medica GPS integration
● COTS software	Integrated functionality of the above

Figure 3

Each site possesses a distinct relationship for both receiving and providing support to other elements of the telemedicine network (see figure 4). The network operates under two integrating principles. All telemedicine support is demand activated by the end user at the front line and all requests for telemedicine support follow the typical path of patient evacuation. The end user retains control of the technology and uses it when needed in a practical situation as opposed to a project designer trying to force a new technology into situations which may not benefit the healthcare provider and his patient.

<i>T-Med Node</i>	<i>Manned by-</i>	<i>T-Med Capability</i>	<i>T-Med Clinical Activity</i>
● 3 Outposts on Macedonian Border	Company aidmen, combat lifesavers	Inmarsat M, delayed video, still image, data, voice, & fax	Consultations w FAS & MAS-Patient Video Soap Notes Patient Data & Fax
● Fwd Aid Station (FAS)-Skopje Fwd	Phy Assistant(PA) & medics	Inmarsat A, Patient video, still image, data voice & fax	Support for Outposts-Consults with MAS, Patient Video Soap Notes
● Main Aid Station (MAS)-Skopje Rear	Gen'l Med Officer (GMO), PM tech Vet tech, & aidmen	Inmarsat A, Patient video, still image, data voice & fax	Consults with FAS & Outposts, Evac Consults with ATH, Grnd Rnds-LARMC & WRAMC
● 48th Air Trans Hosp (ATH) Zagreb	GMO's, general surgeons, & some specialty physicians	Inmarsat A, Patient video, still image, data voice & fax	Consults with MAS Evac Consults with LARMC Grnd Rnds-LARMC & WRAMC
● Landstuhl Army Regional Med Ctr (LARMC)-Germany	Tertiary Care Medical support	Terrestrial 56, Patient video, still image, data voice & fax, Inmarsat A	T-Med host for all operations in Zagreb & Macedonia
● Walter Reed Army Med Ctr(WRAMC) Wash, DC	Tertiary Care, Consultant-level, & GME medical support	Terrestrial 56, Patient video, still image, data voice & fax	T-Med host for all operations in Zagreb & Macedonia Backup for LARMC
● T-Med Project Office Ft Detrick, Md	Project Operational Support	Terrestrial 56, Patient video, still image, data voice & fax	Operational Tech support Multimedia Medical Flight Recorder Database

Figure 4

Project ProMED

Frequently, the time period between a physician deciding to take an action on a patient (obtain a chest x-ray or write a prescription) until that action is completed is lengthy. For example, during early morning ward rounds a physician decides to order a medication on one of his patients. The order is written sometime after the entire rounds are completed (1 hr.). Then a nurse takes orders off of the patient's chart (3-6 times/day). A "runner" takes the requests to the pharmacy (every hour). Later that day the patient actually receives the prescribed medication.

We see an opportunity to improve the physicians productivity and better serve patients by improving the information pathway. Recently Personal Digital Devices (PDAs) such as the Apple Newton have become available. These hand-held (4 inches by 7 inches) devices are like small personal computers with built-in communication

functions (pager, fax, infrared wireless communication), and some first generation hand writing recognition capability.

With a PDA, a physician can write orders for his patients as he does ward rounds. The order is immediately passed via wireless infrared communications to the proper location i.e. prescriptions are send directly to the pharmacy. This can significantly decrease the turn-around time from when an order is requested until it is completed. Also, cost comparisons of alternative drugs to prescribe can be stored and presented to the physician for consideration. Automatic drug interaction warnings can alert the physician of possible problems.

The U.S military in a cooperative research program with Apple Computers have set up 3 test sites to evaluate the Newton for use in medicine. Walter Reed Army Medical Center in Washington, D.C., Wright-Patterson Air Force Medical Center in Dayton, Ohio and Brooke Army Medical Center in San Antonio, Texas are presently evaluating the technology initially with a Smart-Rx (pharmacy order system) and a form generator for patient history and physicals and nursing notes.

Conclusion

Technology is exploding, yet at the same time resources within medicine are shrinking. The rapid prototyping format utilized by the project office helps to convert newly developing technologies into the medical field in a timely manner.

Supported by a diverse group of experts from various fields, physicians (as the end users) drive the requirements to keep the technology integrated useful and practical. The goal is to apply developing technologies into the medical field in an attempt to improve patient access and improve patient care, but at the same time decrease healthcare costs.

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The Use of Teleradiology in Military Medical Field Exercises

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INTRODUCTION:

Teleradiology is commonly used in transmitting and receiving images from the office for preliminary interpretation by on-call radiologists or from fixed, underserved remote sites to a central facility for primary interpretation or consultation. In addition, military hospitals without full-time radiologists have used teleradiology to send cases to large civilian institutions for primary interpretation.¹ During Operation Desert Storm in 1991, selected CT images and radiographs were sent from Saudi Arabia to Brooke Army Medical Center in San Antonio, Texas via satellite and telephone linkages as an evaluation of teleradiology potential from the battlefield.² As this was a very large scale deployment, the amount and weight of the equipment used were not very critical. Many military deployments are smaller and shorter where weight and cubic volume may have an important impact. The feasibility of teleradiology as a support tool and a deployable asset was evaluated by using two different commercial teleradiology systems in two field exercises in 1993.

MATERIALS AND METHODS:

In May and October 1993, members of multiple Army and National Guard medical units from South Texas assisted the Texas Health Department in providing health education, screening exams and basic medical services to residents of Starr County, Texas, the poorest and most medically underserved county in Texas. The facilities used were in Rio Grande City, which is situated by the Mexican border and 250 miles south of San Antonio (figure 1). One aspect of the services provided was taking and interpreting PA and lateral chest radiographs of patients with positive PPD test. A Continental X-Ray ISOshelter and an adjoining three-section temper tent were erected as the radiology department. An ISOshelter is a standard-sized, prefabricated metal-sided building used in the Department of Defense Deployable Medical System (DEPMEDS) of combat hospitals. Each unit measures approximately 8 foot x 16 foot x 20 foot expanded and can be transported by trucks or transport planes. Each shelter also contains specific equipment for its



Figure 1: Map of Texas showing the cities described in text.

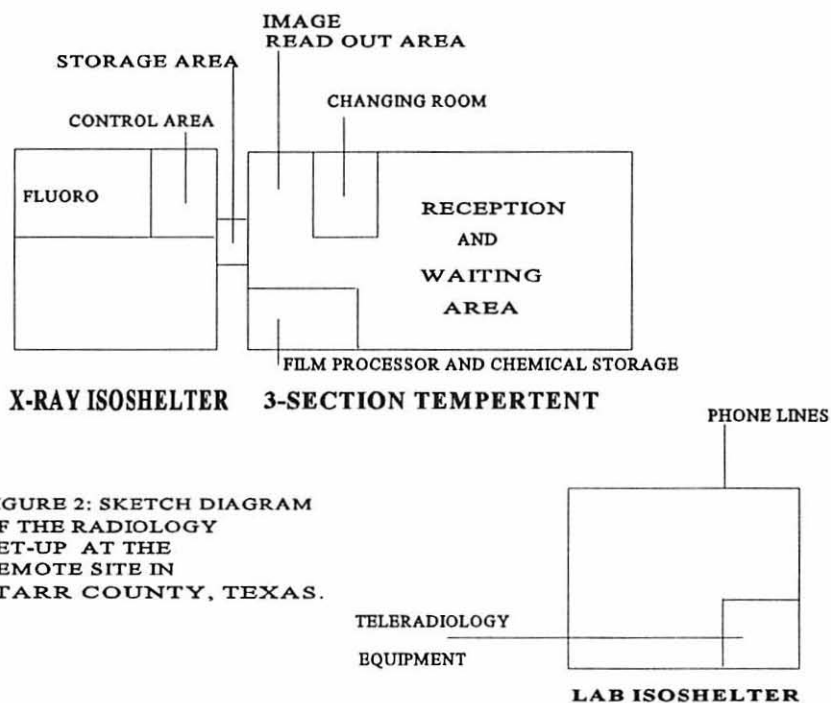


FIGURE 2: SKETCH DIAGRAM OF THE RADIOLOGY SET-UP AT THE REMOTE SITE IN STARR COUNTY, TEXAS.

designed task such as radiology, laboratory, or maintenance. This temporary radiology department had all routine X-ray equipment which include fluoroscopy and a film developer, film interpretation area, a storage area, a changing room, and a reception/waiting area (figure 2). The commercial teleradiology systems consisted of a film digitizer, a control computer (Intel 486 based), a 1K or 2K resolution video monitor, and communication links. The teleradiology equipment was set up in a corner of the laboratory ISOshelter located about 40 feet from the main radiology area instead of inside the temper tent to decrease dust exposure. The telephone service consisted of two GTE voice-grade lines (one for image transmission, the other for voice communication). Digitized images were stored on hard disks in either 8 or 12-bit pixel depths with 1K or 2K matrices. Transmission of stored images was in the form of 1K or 2K data sets with 8 or 12-bit depths and 3:1 lossless compression using a 14.4K bps modem. Telephonic discussion of the cases transmitted was made between radiologists at both ends of the communication link after independent interpretations.

FINDINGS:

Fifty one images were transmitted during the first exercise and forty images were sent during the second exercise. In both exercises, the difference in contrast and, thus, diagnostic sensitivity between 1K resolution 8-bit deep and 1K resolution 12-bit deep images were significant enough that only 1K resolution 12-bit deep images were transmitted after the first few cases. The average transmission time for each 1K resolution 12-bit deep image with 3:1 lossless compression was about 5 minutes 30 seconds using the 14.4K bps modem. The transmission cost for each image was about one dollar and 25 cents, assuming a telephone charge of 18 cents per minute for high volume users. During the first exercise, there were multiple rainstorms during which the transmission time either was prolonged by many minutes due to noise interference which decreased the effective transmission rate of the modem or complete images had to be retransmitted in whole due to loss of telephonic connection between the sites. The presence of a viewing monitor at the sending site was found to be very helpful. This allowed the sender to check the quality and the orientation of the image before sending it, thus, saving money and time by not initially sending poor quality images. The first teleradiology trial was conducted without such a viewing monitor at the transmitting site. The sender can also use the monitor to adjust the contrast level and range, and to magnify specific areas of the stored image. This allowed somewhat improved diagnostic sensitivity by the radiologist at the transmission end in evaluating suboptimal radiographs without having to reexpose the patient. Only a few 2K resolution 12-bit deep images were transmitted as a test because the 1K resolution 12-bit deep images in this trial were found to be of sufficient diagnostic quality for these screening

examinations and the total transmission time of approximately 25 minutes per image of the higher resolution images was much longer and more expensive using the trial communications equipment. One unexpected benefit of the teleradiology system was the use of its archiving ability. Due to the suboptimal field condition, the film processor occasionally did not function properly and produced physically unstable film images. These particular films' emulsion lost its contrast over a short time, and started to flake off with routine handling. The archiving capability allowed these disintegrating images to be saved at their best condition for future reference.

CONCLUSION:

Teleradiology from a remote site during field exercises is possible. Thus, it can be used in rapid deployment situation, disaster relief, indigent health support, etc. A viewing monitor at the transmitting end is necessary for smooth transmission operation and assists in easy case discussion and consultation between the sites. It may even be helpful in evaluating suboptimal films without repeatedly exposing the patients to radiation and can be utilized in the review of radiographs stored in the digital archive at the transmission site. The best trade off in terms of image quality, transmission time and expense for our limited population was to store and transmit the radiographs as 1K resolution 12-bit deep data sets with 3:1 lossless compression.

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MDIS Teleradiology in North America

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I. Introduction

The Medical Diagnostic Imaging Support (MDIS) system is a large project installing Picture Archival and Communications Systems (PACS) and teleradiology at numerous military medical facilities in the U.S. and overseas using a network of computer-based digital devices that electronically manage diagnostic images within a medical treatment facility and its region, regardless of physical distances. MDIS' functional specifications were compiled by a composite team of radiologists, physicists, clinical engineers, hospital administrators, technologists, and computer systems/communications specialists. As teleradiology sites become operational, we are developing a better understanding of the capabilities and limitations of the technology¹⁻⁴. All PACS sites are also capable of functioning as teleradiology hubs. Presently, Madigan Army Medical Center, Brooke Army Medical Center, Wright-Patterson Air Force Medical Center, David Grant Air Force Medical Center, and Wilford Hall Air Force Medical Center are undergoing phased implementation of this system. Teleradiology implementation first began at McConnell Air Force Base, Kansas, in the Summer of 1993. Teleradiology sites in progress include: Holloman Air Force Base (New Mexico), Cannon Air Force Base (New Mexico), Dyess Air Force Base (Texas), Davis Monthan Air Force Base (Arizona), and Mountain Home Air Force Base (Idaho). Several other sites are scheduled for implementation in the continental United States and Hawaii in 1994-95.

II. Operational Description of the MDIS Teleradiology System

The ultimate success of teleradiology depends on acceptance by the end users - the physicians. Physicians in a managed health care system require several major areas to be addressed in the ideal situation. A teleradiology system needs high image quality, a user-friendly interface, qualified radiologists interpreting images, close communications between the clinician, radiology technologist and radiologist, and images rapidly accessible to the clinician with a dictated report tied to the image. Radiology departments require a highly reliable system with the freedom to shift workloads as necessary within and between health care facilities, and a large database of images for education and research purposes.

The MDIS teleradiology configurations address these needs. Full image data sets are transmitted (CR images- 2k resolution, 10 bit contrast ; CT images- 512 resolution 12 bit contrast) from the spoke and then viewed on high resolution (2K) monitors at the hub. All workstations in PACS and teleradiology sites utilize the same user-friendly Macintosh interface. Good communications are maintained with an integrated teleconferencing system. The T1 line is multiplexed such that 22

channels are used to send radiographic images and 2 channels are used to transmit compressed audio/video to allow real-time interaction between sites. A radiology information system (RIS) is integrated into the process such that every image is tied to the patient's demographic information, clinical history, and radiological report. Two-way teleradiology between sites allows workload sharing, peer review, research, and educational opportunities.

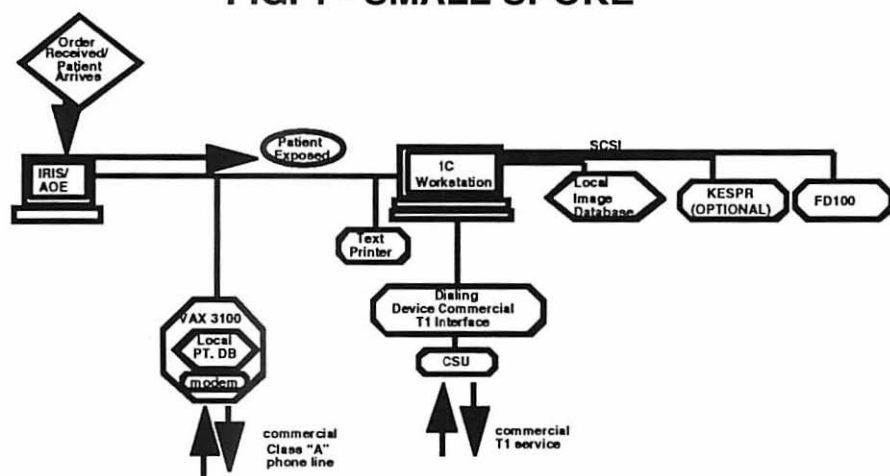
Plain radiography images (chest, bone, abdominal series) can be acquired electronically either by laser digitization of radiographic film or by use of computed radiography (CR). The CR system acquires digital x-ray images directly without film by utilizing reusable phosphor plate technology. Exposed plates are scanned electro-optically to extract images in digital format [5]. The teleradiology network can also support the transfer of images directly from existing digital imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US). These digital images are passed to the network, through gateways, for diagnosis, optical archiving and image management.

Digital images from remote spokes are received at the central hub and transferred by the network into an on line computer memory called the Working Storage Unit (WSU). Images on the WSU are compressed approximately 2:1 losslessly using a discrete cosine transfer protocol [6]. Once in the WSU, the images are available for "soft copy" (filmless) interpretation and diagnosis by radiologists. Radiological diagnoses are then transcribed into the database and electronically sent back to remote sites for automated printing on laser text printers. Following interpretation, images from the WSU are automatically archived onto optical platters housed within an Optical Disk Jukebox (ODJ). Images are lossy compressed 10:1 using a modified JPEG protocol. Each optical platter is capable of permanently storing approximately 10,000 chest equivalent digital images (compressed) and related reports, for a total of approximately 1 TeraByte of digital information on a 100 platter ODJ. The ODJ contains dual robotic mechanisms for high speed access of archived images [7].

III. Architectural Application of the MDIS Teleradiology System

Figure 1 shows the basic architecture of a small spoke in the MDIS teleradiology architecture. The small spoke architecture will support a facility which generates up to 100 images a day. It is configured with a single, image-capable workstation (1C Workstation) which is multi-purposed, serving as Computed Radiography Acquisition Workstation (CRAW), Film Digitizer Acquisition Workstation (FDAW), Teleradiology Server (TRS), and Quality Control (QC) station. The workstation conducts its support activities serially; each service must complete before the next support activity can start. The separate Integrated Radiology Information System (IRIS) has been incorporated so radiology reception and administration activities can be performed in parallel with exam acquisition. Figure 2 shows the basic architecture of a large spoke. The large spoke architecture will support a facility which generates up to 350 images a day. It is configured to support greater workload requirements and local primary reading functions. To support the increased workload, additional acquisition workstations were added to provide greater parallelism in acquisition operations.

FIG. 1 - SMALL SPOKE



The flow of a radiology exam at the small and large spokes follows:

Patient enters radiology reception, Local Database Query: Is Patient Known? Yes: Order Scheduled / Patient "Arrived", No: Patient entered, demographic data entered, order scheduled/patient "Arrived"

Local Database is Updated with Patient Information, Exam is Scheduled/Ordered Upon Arrival, Bar code is printed or Acquisition Worklist Updated

1-C Workstation Functionality.

In CR-based small spoke application: Exam Initiated (Bar Code, Acquisition Worklists), Verify Patient Data / Exam Priority (STAT, Wet, Routine), Read CR Plate / Stored to local disk, Conduct QC, release patient. In FDAW application: As applicable, initiate historical exam & digitize related historical images.

Image, Patient, Exam data is transmitted to designated reading location, via the teleradiology gateway server, in either Automatic Batch mode or STAT mode or

Manual push to any configured location.

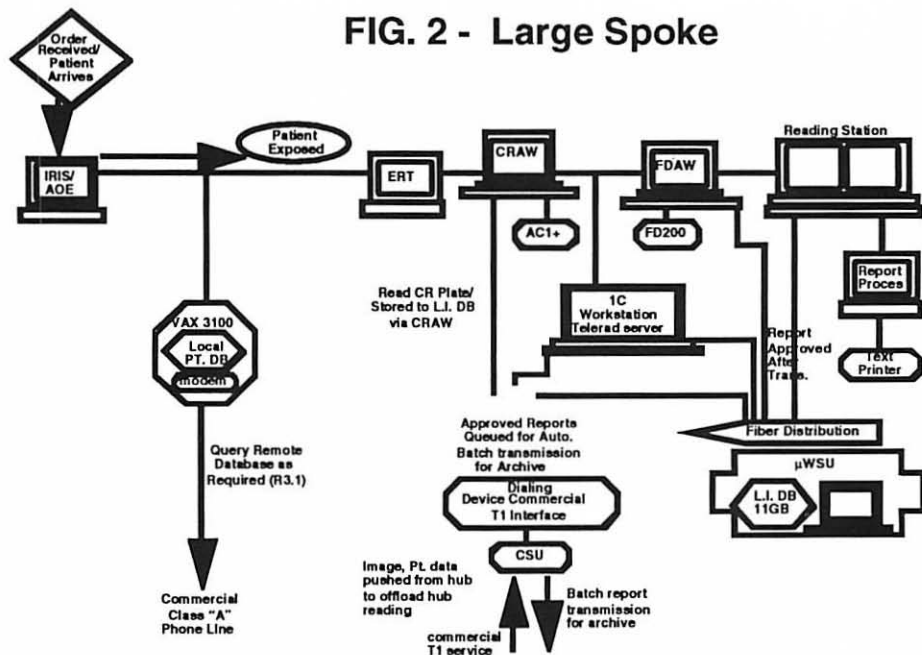
Exams pushed from spoke stored on and read from local disk at reading location.

Report transcribed to database, Reports available for manual push to spoke if requested, Reports are available for view (prior to approval) via a remote query from spoke.

Automatic Transmission of Report back to spoke.

The Large Spoke architecture provides a diagnostic reading station (two 2K monitors) for local reading by the radiologist. A micro-WSU allows for multiple clinical workstations to be added with no degradation in system performance. The additional workstations are required if a site is utilized in the filmless mode.

FIG. 2 - Large Spoke



The hub shown in figure 3 can be configured with a WSU or a micro-WSU. Note that the "pure" hub does not contain any image acquisition devices; it is used for reads and archiving for remote teleradiology sites only. However, with the addition of a WSU and the desired image acquisitions components, it may be utilized as a full PACS.

The hub provides the permanent legal record archive of all images sent to it from the spokes. A radiologist at a spoke will "call-in" to the hub to retrieve old exams for comparison with current exams. The exams will be retrieved from the hub's ODJ and sent out via the 1.54 Mbit/sec T-1 line. The hub and spoke can also connect to each other via VAX modems. The VAX modems allow for remote access for software upgrades and database maintenance.

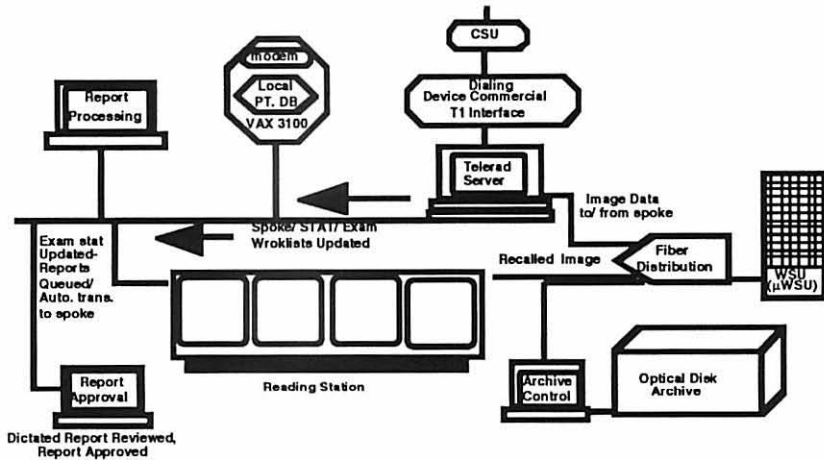
In addition to the small and large spoke teleradiology configurations, the architecture of a "micro-spoke" has been developed. The micro-spoke is a low cost "bare-bones" system that allows a low usage remote site to send full resolution images to a hub for primary diagnostic interpretation and archive. The current version of the micro-spoke includes a film digitizer, a workstation, and a teleradiology gateway server.

IV. Lessons Learned

The military has several small medical treatment facilities in rural America, some in very remote sites. At a low workload site where a radiologist must be present due to the types of radiology procedures being conducted, we can send

additional studies to be read, thereby maximizing his utility. Traditionally, sites with only one radiologist get into trouble when the radiologist is on vacation, sick, or on temporary duty elsewhere. Now, with MDIS teleradiology implemented at these sites, images can be routed to another site for interpretation. Also, given the ability to send any image to any site in the teleradiology constellation, a radiologist at a remote site can receive images not normally available (CT and MRI) to maintain their skills. Clinicians also benefit from having imaging studies sent to their sites which present unusual or interesting cases.

FIG. 3 - Hub: Reading &/ or Archive Location



Full clinical use of MDIS teleradiology will begin in late 1994; however, several system parameters have been evaluated to date. Image display times at a large spoke average three to four seconds for screen paint time from intermediate storage (micro-WSU). Image transmission time (chest radiograph) from a spoke to a hub takes one minute fifteen seconds per image. Filmless imaging and interpretation at Fort Detrick in Frederick Md. has been tested successfully and is ready for daily operations.

When fielding a teleradiology system, the lines of communication between all participants in the implementation activity must be strong, well coordinated and very cooperative to be successful. Key elements of communication include defining good operational and clinical scenarios, properly designing the systems to support the scenarios, and then ensuring that shipping, installation, integration and training processes are closely coordinated and tracked. It is very important to involve the sites' personnel as much as possible, and help them develop accurate and reasonable expectations of upcoming events. Designating key clinical and technical points of contact at each site is essential to developing clinical and operational scenarios that make sense.

Training of site personnel needs to be strategically planned and implemented if it is going to be effective. Training needs to be accompanied by site specific Standard Operating Procedures and well documented contingency plans. The addition of video teleconferencing capability is extremely useful to support training, radiology consultation, maintenance, and enhancing radiologist/clinician professional relationships.

V. Conclusions

Teleradiology provides immediate qualified radiology support to sites that would normally wait days for diagnostic interpretations of their images. The teleradiology support of clinical consultations allows the "experts" to be shared by all. Through the use of existing communications lines, the military is able to provide instantaneous interpretation of emergency radiological exams and 24 to 48 hour turnaround on routine images. With an integrated RIS, teleconferencing system, and two-way transmission of images, we are developing a virtual radiology department that is truly time and distant independent. Using the system to balance workloads, decrease report turnaround times, and access subspecialty experts, we hope to simultaneously decrease costs and improve patient care in our remote medical treatment facilities.

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SESSION 10

PACS Software

Chair: Seong K. Mun

A Novel Software Architecture for Digital Radiography Systems

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1 Introduction

This paper describes a novel approach at the design of the system software that has several advantages over traditional proprietary system architectures.

This design methodology was successfully applied in the Thoravision digital chest radiography system [Phi92].

The first design proposal for this system was very complex and relied heavily on the use of proprietary software and internal interfaces that were developed in another group within Philips in Holland. It soon became obvious that the training and communication effort between the development groups was becoming tremendous. Moreover the original design was complex enough to seriously endanger reliable operation.

For these reasons we decided to design the system in a novel way. Although a remotely similar approach is described in [FBP92] for a research system, we know of no other commercial systems employing this strategy.

2 Overall design

When we designed the software architecture for the system we had the following goals in mind:

Reliability As a medical system the system should be very reliable. This means that all components should be as failsafe as possible, and that the interaction of components should be fully tested. It also means that recovery from failures be graceful.

Simplicity The architecture should be "as simple as possible, but not simpler."

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Flexibility and extensibility The system should be flexible and easily extensible. This includes interfacing to new modalities and third-party equipment, implementation on different hardware platforms, as well as upgradability.

Rapid implementation The design should encourage rapid development and implementation.

To realize these goals we thought that the following criteria would be helpful:

openness As far as possible, software and interfaces are either based on standards or industry standards, or are publically documented.

modularity The architecture should be modular.

To satisfy the openness goal, we chose the following industry standards as a development base: the Unix operating system, the X Window System, the TCP/IP protocol suite, and the OSF/Motif Graphical User Interface.

The software was implemented on a general-purpose workstation with only minimal proprietary hardware attached to it. Some hardware was developed in-house, because at that time no vendor could supply hardware that matched our specifications.

To achieve the modularity goal, the overall architecture is based on a set of modules communicating via messages. The modules were implemented as Unix processes. The interprocess communication (IPC) was based on standard Unix facilities that are well-tested and reliable. All messages are gatewayed through a central process, that forwards them to the appropriate processes.

3 System structure

The system structure implements a clear division between the hardware and the system software. The hardware is completely managed by the "system controller", which is an independent microcomputer capable of handling real-time events. It talks to the workstation via the same message protocol as all the other modules. Thus the hardware is not only nicely integrated into our message-based communication mechanism, but it can also be completely simulated via software and separately tested. This also provides for hardware independence.

The image processing is done via a set of command scripts written in a general-purpose interpretative language. This language is designed to be easy to use and read, so that technicians and service personnel can do simple customizations, and researchers can develop, implement, and test new kinds of processing easily.

4 In practice

In practice, this design enabled us to assign the implementation of the modules to team members, who could develop and test each module separately.

For testing we developed a generic dummy module, that performed ideally. As the whole state-machine of the system is based on the passing of messages, the dummy module could be implemented as just an application that generated one of the possible messages on the press of a button. Thus the individual module could be completely tested by stepping through the allowed (as well as illegal) messages interactively.

The development was mostly hardware independent. Indeed most of the prototype implementation was done without a real xray hardware behind it, solely based on the specified message protocol.

Although images could not be passed through the gateway as messages, it turned out that the design of the interprocess facility allowed point-to-point links without major difficulty, so that the performance of passing images was adequate.

Besides it's control functions, the ALI image processing language was indeed a very efficient tool for the development and improvement of the basic image processing in the prototype system. It encouraged experimenting with different primitives and parameters, allowed prototyping new algorithms on-the-fly, and supported checking them with different data sets easily. Furthermore, it encouraged stepwise interactive development, because temporary intermediate images could be stored as needed so that lengthy calculations were only done once.

Certain idiosyncrasies of the selenium detector have been compensated on-site via modem and a locally developed scatter compensation technique has been integrated into the system.[FBL⁺93, Lud94] For a more detailed discussion of the ALI language and interpreter see [LP94].

The Motif UIL language allowed rapid prototyping, as well as simple and quick fine tuning.

The use of standard network interfaces facilitated interfacing to PACS and HIS/RIS systems at some sites.

The software has successfully been used over an optical fiber connection between the Duke Hospital North and a research lab in the Department of Radiology.

5 Results

As shown in the above sections, our design has a number of advantages, both in the development phase as well as in the application phase, as exemplified by the system installed at the Duke University Medical Center:

Testability The system is extremely testable, through the use of a set of small precisely defined modules that can be independently developed, imple-

mented, and tested. Moreover, the implementation of the system state machine as a whole can be very easily debugged by monitoring the central gateway process.

Maintainability The system is easily maintainable as necessary changes can be easily integrated and tested. In addition, problem fixes and other changes should only have local effects in one module, as modules are disassociated via the message passing.

As we make heavy use of industry standard software and interfaces, externally available maintenance personnel can service the system with only moderate effort.

Portability Through the use of standard interfaces the system is fairly portable to new host system architectures.

Rapid implementation Because modules can be independently developed, parallelization in the development is possible.

Use of standard software requires only minimal training effort for new project members.

Flexibility The individual modules could easily be distributed across machines, or across CPUs within one machine.

Extensibility The system is very easily extensible, because the only change needed to incorporate a new module, is adding the process to the system and adding appropriate messages.

By using an interpreted language for the image processing subsystem, on-site configurability is enhanced and factory extensibility is greatly facilitated.

Networking Through the use of a standard networked graphical user interface and the use of an interprocess communication mechanism that works across the network, the system can be easily distributed. Moreover, telera-diology is a just a matter of configuration and suitable network technology.

6 Acknowledgments

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Parallel Programming Implementation of Computed Radiography Preprocessing Tasks

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EXPANDED ABSTRACT

The image pre-processing tasks involved in preparing a computed radiography (CR) chest image from its original raw data format to that compatible for display at the viewing workstation include: image reformatting, background removal, image orientation, default optimal look-up table calculation, and auto-contrast enhancement. The CR image reformatting routine involves standardization of the image header, image size and image format to an ACR/NEMA DICOM3 compatible file format. The task of background removal is necessary to eliminate the potentially distracting unexposed (white) background due to x-ray collimation at the time of exposure [1]. In the image orientation program, the original image object orientation is determined and image rotation is performed to re-orient the image to a standard viewing position [2]. The generation of default look-up tables for initial display parameters for CR images is based on the anatomical region, the image histogram and the minimum and maximum gray levels from which a default optimal display window and level are calculated. In an effort to provide further automatic display window and level optimization, piecewise-linear look-up tables are generated for auto-contrast enhancement of the different tissue densities (i.e., radiographically soft tissues such as muscle, fat and overpenetrated lung, and radiographically dense tissues such as mediastinum, subdiaphragm and underpenetrated lung) within a chest image [1].

Currently, these tasks which are all computationally intensive, are done sequentially, and at separate computing resources. As a result, the operating environment is not optimized and computing resources are wasted. Each of these pre-processing algorithms share significant amounts of commonality. The goal of this paper is to exploit these commonalities, consolidating similar tasks using a parallel paradigm irrespective of a specific supercomputing or multiprocessor architecture, resulting in a streamlined operating environment and maximized computational efficiency.

The standard serial approach for each of the CR image preprocessing tasks will be described followed by an analysis of the commonalities among these tasks and a description of the parallel paradigm designed for preparing CR raw image data for display at a picture archiving and communication system (PACS) viewing workstation. Results will be presented comparing computer execution time for the

standard serial approach versus the computation time saved by exploiting method commonalities. A discussion of several parallel approaches concludes the paper. The parallel programming paradigms presented here include a purely "software parallel" solution, a combination software-hardware schema utilizing the "poor man's parallel computing architecture", and a moderately hardware-dependent implementation of CR preprocessing tasks on a Sun 690/MP using multi-threading, multiprocessing.

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Application of Wavelet Compression to Digitized Radiographs, CT, and MR

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Introduction

Digital image data compression is an enabling technology for the cost effective implementation of both Picture Archiving and Communications Systems (PACS) and teleradiology. Sufficient levels of data compression can make the implementation of partially or fully digital radiology departments more practical using existing transmission and storage media. With respect to teleradiology, data compression reduces bandwidth requirements and allows cost-effective delivery of expert interpretive services to remote areas (domestically or abroad) that do not have access to advanced telecommunication infrastructures. Lossless compression techniques are limited, only capable of achieving compression ratios in the 1.5:1 to 3:1 range [1,2]. To significantly impact storage and transmission costs, compression ratios on the order of 20:1 or higher are required for plain films. Lower compression ratios may be sufficient for cross-sectional imaging modalities which are inherently of lower resolution. Substantial levels of compression can only be achieved using lossy techniques. Lossy compression implies that some information is lost in the compression/decompression process, but algorithms are designed to minimize the effect of data loss on the diagnostic features of the image [3].

Wavelets, discovered in 1987 [4], offer an alternative to JPEG (Joint Photographic Experts Group) [3,5,6] and other discrete cosine transform (DCT) based compression algorithms [7,8]. The JPEG method suffers from blocking artifacts that become more evident with increasing compression ratio [9]. The purpose of this study was to evaluate the potential application of wavelet compression to digitized radiographs and cross-sectional images.

Wavelet Compression Technique - Radiographs

A mathematical description of wavelet expansions is beyond the scope of this presentation, but review articles are available for the interested reader [2,10,11]. The data compression algorithm used is a commercially available software package (Aware, Inc.; Cambridge, MA) for gray-scale image compression. For radiographs, the algorithm uses a proprietary implementation of compactly supported wavelets for 2-D image compression that was not optimized for use with medical imagery. Similar to other transform compression algorithms [3,12] the wavelet technique requires three main steps. These include a transformation of the image data using a pre-defined set of basis functions, quantization of the basis function coefficients, and coding of the resulting data set to remove redundancy. There are an infinite number of possible wavelet expansions which, by definition, must meet certain mathematical constraints [13]. Different sets of basis functions may be more applicable to specific imaging

tasks. Wavelet expansions are multiresolution and orthogonal. Orthogonality implies that there is no redundancy in the information carried by the coefficients of a wavelet expansion. From a signal processing standpoint, one may view the image data as a signal which has high frequency (high spatial detail) and low frequency (smooth) components. The algorithm filters the signal (image data) into high pass (i.e. high spatial frequency) and low pass components. This process is then iterated on the low pass component – typically 5 to 9 times. The resulting decomposition of the data is then represented by a multiresolution set of basis functions. The basis functions used in the Aware algorithm were discovered by Daubechies – and the Daubechies wavelet basis designated D3 was utilized [4]. This series has performed well for a variety of gray-scale image compression applications [13]. Once the image has been transformed to a wavelet representation, the basis function coefficients are quantized, which results in many of the coefficients being rounded to zero. The final resulting data set is encoded using a lossless technique, similar to modified Huffman encoding, to eliminate redundancy. The only variable under user control was the desired compression ratio.

Digitized Radiograph Study

- Twelve plain film cases with a variety of abnormalities were digitized using a Dupont (FD-2000) film digitizer (resolution 1684 x 2048 x 12 bits) then compressed (ratios 10:1 to 60:1) and decompressed on a SparcStation 10 (Sun Microsystems; Sunnyvale, CA). Image compression took approximately 20-30 sec and decompression was slightly faster.
- Images were presented on a two-headed, high-resolution (1792 x 2252) diagnostic workstation (RSTAR, Inc.; Cambridge, MA).
- Images were displayed in pairs such that at least one of the two images was always an original and the other was a compressed/decompressed version of the same case. Control cases consisting of two original (uncompressed) images were also included.
- Image pairs were presented in random order to seven board eligible/board certified radiologists.
- Readers were asked to respond to the following questions:
 1. Is there appreciable image degradation? If so, in which image?
 2. If degradation is noted would it impact diagnosis of the case?
- Readers were required to adjust contrast and magnify portions of the image to evaluate the robustness of the compression algorithm.
- Quantitative measures of image quality were calculated including the average error per pixel and the root mean squared error (RMSE).

Results with Digitized Radiographs

A sample compression of a chest radiograph is shown in Figure 1. The graph of perceived image degradation vs. compression ratio (Fig. 2) shows a sigmoid shape with the steep portion of the curve centered at a compression ratio of 30:1. Analysis by image type (Fig. 3) shows that bone films were more frequently judged to be degraded than chest films although the trend was not statistically significant. The perceived degradation was judged to be of diagnostic significance in only a small percentage of cases. Only one image was judged to be significantly degraded by one reviewer at a ratio of 30:1 (subtle cortical resorption in a patient with hyperparathyroidism). No other degradation was judged to be of diagnostic significance below a ratio of 40:1. Quantitative error measures (average error per

pixel and RMSE) increased at a much slower rate than the associated compression ratio.

Advantages of Wavelets

Many radiologists will be familiar with the fast Fourier transform (FFT) due to its wide application in MR imaging. The FFT represents image signal as the sum of sines and cosines which are the basis functions of the transformation. The compactly supported wavelet transformation offers several advantages over the FFT. Wavelets are particularly well-suited to accurately depict localized phenomena which are highly relevant in medical imaging applications. Wavelets are much more efficient in depicting abrupt changes and edges than is the FFT. Another advantage of wavelets compared to other transformations (such as the FFT and DCT) is that they constitute a multiresolution representation. The scale of multiresolution basis functions varies logarithmically rather than linearly. Importantly, human sensory systems, including the visual system, process information in the same manner. Another advantage of wavelets is their computational efficiency [2,13]. "Wavelets are able to capture the behaviour of complex, nonlinear dynamical systems with an accuracy and speed not possible with known alternative techniques [2]."

Alternative means of compression are available or under investigation. The most widely employed algorithm is probably the DCT-based JPEG method [3,5,6] although other variations are under investigation [7,8,14]. The full-frame DCT technique [1,15,16] has received attention in the radiologic literature. Using the full-frame technique the maximum computational complexity of the task increases linearly with $n \log(n)$ where n is the number of pixels. The computational complexity of performing the DCT on the whole image without dividing it into smaller blocks (as done by JPEG) is so large that specialized hardware may be required for near real-time applications. On the other hand compactly supported wavelets increase in computational complexity linearly with n [2]. This translates into faster compression which does not require extensive computing power or specialized hardware. While the full-frame DCT approach is computationally intensive, ROC studies using this technique with chest radiographs have shown that observer performance is not significantly affected at compression ratios of at least 20:1 [1,14].

Based on our initial experience, including nearly 600 observations, we believe that compression ratios of at least 20:1 are achievable for digitized radiographs using compactly supported wavelets without sacrificing diagnostic image content.

Application of Wavelet Compression to CT and MR

As image matrix size decreases for modalities such as CT and MR, compression becomes more challenging. Typical matrix sizes are 512 x 512 for CT and up to 256 x 256 for MR. The decrease in matrix size relative to radiographs limits the degree of redundancy which may exist and hence the level of compression which can be achieved. Using the full-frame DCT technique, Chan et al. achieved compression ratios of approximately 5:1 for CT and MR [16]. To process cross-sectional images, the wavelet algorithm was modified (Aware, Inc.; Cambridge, MA) to perform 3-D compression. In 3-D compression, the software views sequential CT and MR slices as comprising an imaging volume which is compressed simultaneously [12]. The algorithm takes advantage of redundancy between adjacent slices enhancing performance.

Initial subjective experience with wavelet-based compression of CT suggests that ratios on the order of 10:1 to 20:1 may be clinically acceptable. A sample compression of a liver CT is shown in Figure 4. Compression of MR images is more complex. Achievable compression appears to vary with the pulse sequence used as well as the body part being examined. For example, for brain MR compression ratios on the order of 7:1 to 10:1 appear subjectively acceptable. Subtle textural changes are appreciable on T1-weighted images at a ratio of 10:1 when using magnification. These changes are less evident on the associated T2-weighted images. For body MR, ratios on the order of 10:1 to 15:1 may be acceptable. As with brain MR, the T1-weighted images appear slightly more sensitive to the algorithm than T2-weighted images. The increased sensitivity of T1-weighted images to compression may relate to differences in signal-to-noise. T2-weighted images have lower signal-to-noise and hence algorithms which preferentially eliminate noise will have a performance advantage. Similarly, body images are noisier than brain images, possibly accounting for the superior performance of the algorithm with body studies.

Summary

Image compression is an enabling technology that makes PACS and teleradiology systems more practical and cost-effective using available storage and transmission media. Our initial experience indicates that wavelets can be applied to the compression of both digitized radiographs and cross-sectional images. Based on our initial subjective analysis, compression ratios of at least 20:1 appear acceptable for digitized radiographs. 3-D wavelet techniques offer great promise for compression of CT and MR images, although the degree of acceptable compression is limited by the smaller image matrices relative to radiographs. Optimization of the compression algorithm is expected to yield higher levels of compression for all image types.

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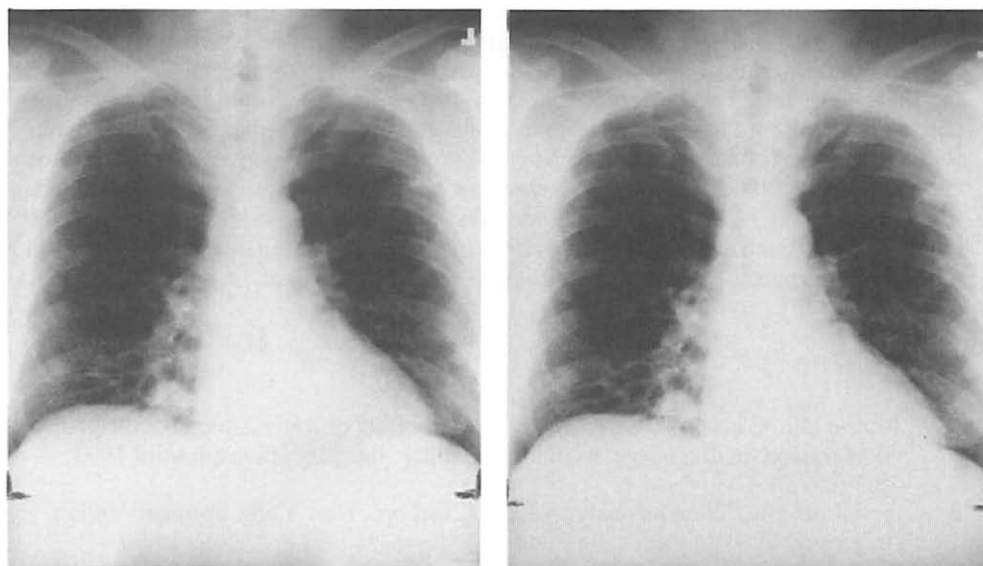


Figure 1. Chest radiograph in a patient with metastatic disease. Original image (left) shows multiple lung nodules. Following compression/decompression at a ratio of 60:1 (right) all of the findings remain visible.

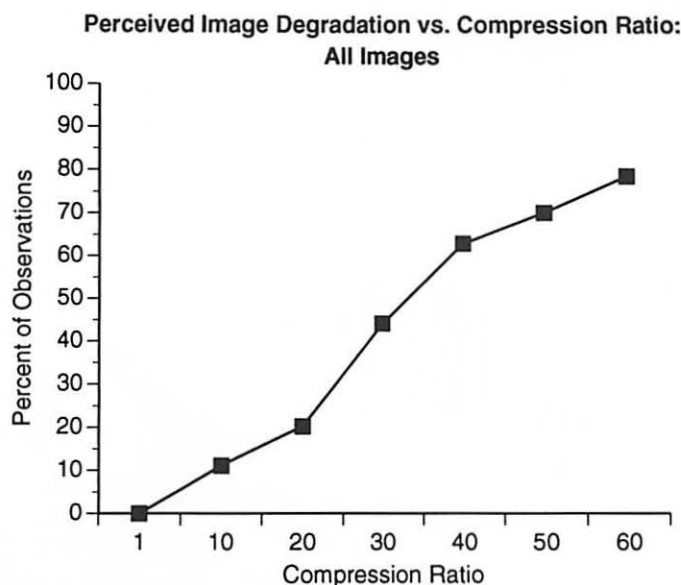


Figure 2. Graph of perceived image degradation vs compression ratio shows a sigmoid shape with the steep portion of the curve centered at a compression ratio of 30:1.

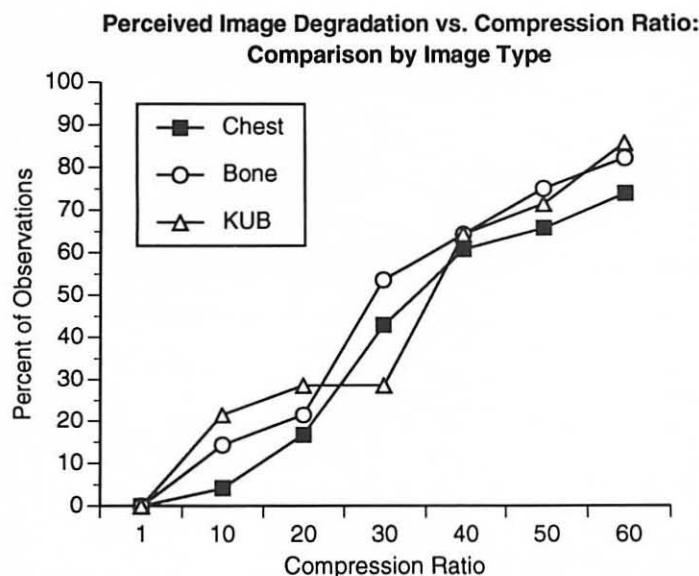


Figure 3. Graph of perceived image degradation vs compression ratio by image type shows that bone radiographs may be more sensitive to the algorithm than chest radiographs, although the trend was not statistically significant.

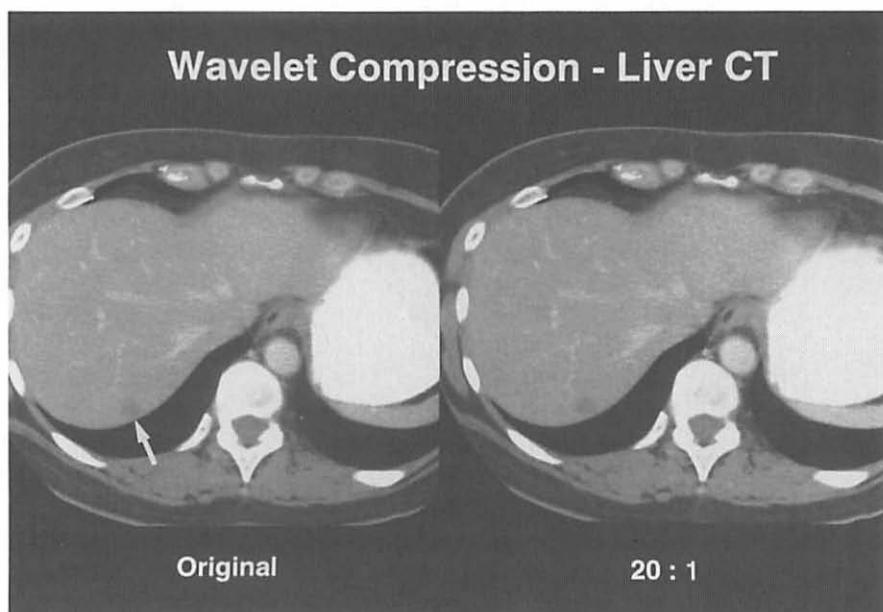


Figure 4. CT scan of the liver in a patient with metastatic disease. Original image (left) shows a small metastatic deposit in the right lobe of the liver posteriorly (arrow). Following compression/decompression at a ratio of 20:1 (right) the lesion remains visible and there is no appreciable degradation in image quality.

Feature-Coded Image Database

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Introduction

Information is a resource that is needed to answer questions, to make decisions, and to perform tasks. The amount of information acquired by the observer will correspond to the difference between what the observer knew after receiving the information and what he knew before. The basic model of information retrieval is simple. Information is stored, and later, when needed, it is retrieved. The only requirement for search is that information be indexed. Indexing defines the accessibility of information. For radiologists, the image is the basic carrier of information. When making a diagnosis, radiologists frequently need access to image collections for reference. One concept for image delivery represents feature-based image database. The radiologic information in the database needs to be organized and indexed in a form that will allow direct access to relevant images. This kind of access will be provided if images are indexed through the image content. The challenge is to determine how to transform radiologic knowledge into usable indices which code image content. When the database is in use, there is potential for a number of communication problems to arise due to incompatibilities between database constructor's indexing language and terminology and that of the user. Depending on the expertise, image findings are reported and communicated at different levels, ranging from a purely perceptual level of the beginner radiology resident to the highly interpretative level of radiology expert. Thus, designing databases with medical images requires to involve structured indexing of image content that will provide the potential for multilevel access to the information store [1]. It is important that the knowledge be represented in form that is compatible with intelligent behavior. Another major technical challenge is to design the retrieval process, from formulation of a query, through the search, to the retrieval of the relevant images. The success that a particular retrieval process will have in meeting this challenge will depend on the way that images are indexed, and the way that the

relevance of images is assigned on the basis of query. There is a need for a language (index) that describes the radiologic images so that they can be tagged for later retrieval. Designers of IMAGE/ICON have developed a prototype of *image description language* for chest pathology that allows dynamic selection of images along relevant *axes* of clinical relevance [2].

We are building a database that will manage heterogeneous (text and image) radiologic data in a way that will make that information easy to store, access, and use. Our goal is to construct an electronic Case Library, a radiology feature-coded image database, that can be searched for a combination of radiologic findings and can offer quality images for comparison to the case in question. To achieve this goal we have designed a *hierarchical image description vocabulary* for image content coding in neuroradiology.

Concept Indexing with Hierarchies

The form of indexing required in a database depends on the types of query that are anticipated. The potential multilevel query formulation needs to be translated into a form that is recognizable by the database. This translation requires an organization of the vocabulary that will be capable of conveying relationships between, and classification of, the terms. The formation of a hierarchy is a useful way of achieving the desired organization. This type of concept indexing requires a representation of the knowledge domain much as is typically seen in an expert system. The integration of a classification scheme that is required for an expert system, with a database system forms the framework of an intelligent database.

For indexing purposes we have designed a *hierarchical image description vocabulary*. We use a semantic hierarchy composed of basic observations and interpretations that form a continuum, in which higher level findings incorporate lower level findings (Figure 1). Using this approach the image details are coded using both basic observations such as CT density of cerebral contents (e.g., appearance relative to brain tissue such as hyperdense, isodense, hypodense, CSF density, below CSF) and higher level findings that express interpretation of basic observations (i.e., calcified, blood, cyst, fat, etc.). The relational database provides necessary flexibility in creating a hierarchy. A hierarchy tree is implemented as a series of records with the record keys representing nodes in the tree. A record key is composed of slots that correspond to the levels in the hierarchy. A slot may typically contain an alphanumeric code of one character (or more) enabling subsequent searching to be made with an alphanumeric key. The first slot of a record key corresponds to the highest level in a hierarchy (root level of a tree) and the last used slot corresponds to the

lowest level in a hierarchy (leaf node of a tree). A record key contains as many slots as there are levels in the hierarchy. A particular record key inherits all of the slots of its immediate parent and uses the additional slot to uniquely identify itself.

The hierarchy can be easily updated and expanded interactively with the assistance from the user.

CT Density

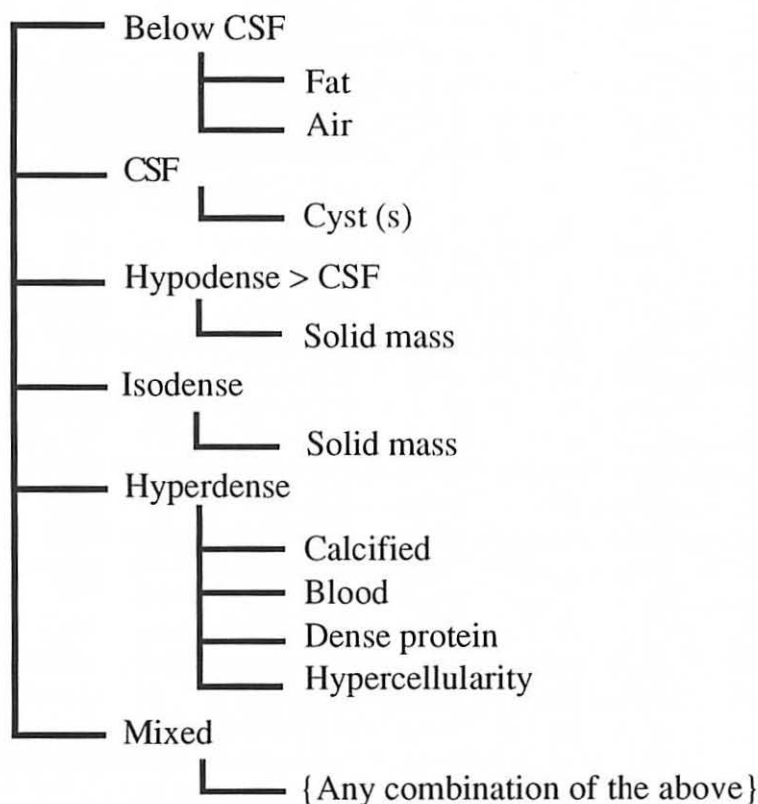


Figure 1. A hierarchy of CT Density concepts.

Query formulation

There are two goals in defining the feature index for coding images: 1) to have a consistent way of coding and 2) to guide image retrieval. As users attempt to find information in the inconsistently indexed database, the inconsistency in indexing will be propagated into uncertainty in how a particular information need concept can be expressed as a query. The development of a well-defined query

language has the potential of improving information accessibility because the searcher utilizes a highly constrained vocabulary correctly. Improved performance is obtained also by simplifying the task of data entry. In our database a checklist type entry form guides the image reader to access and record a value for each radiologic feature. The user may enter as many search criteria as desired and at the level of granularity that the user feels comfortable with. The search criteria are transformed into the search keys in a similar way the record keys are built, with the difference that they can be considered as partial keys. A search in the database with a partial search key would return a selection of records that would belong to a hierarchically organized sub-tree.

Retrieval

Information retrieval is a process where the information needs of the users are compared with the information that is available. Information need is represented as a query, and the potential information (i.e. images) is represented as a collection of index terms which can be matched against the query. Those images whose index representations most closely match the query are then assumed to be relevant and they are passed to the user. We are currently experimenting with different approaches to the matching process to develop representations of the query and image index space that allow measures of similarity to be calculated between queries and images, and to allow images to be sorted according to their similarity or relevance to the query. The present retrieval method is deterministic through a Boolean search. Images are retrieved only if they match precisely the constraints expressed in the query based on a sum of features in the input case that matches cases in the library. Presently there are equal weights on all features considered as important. For each case in the Case Library we use knowledge-based indexing that applies radiologic knowledge to determine which features are important for retrieving each case. As we improve the image retrieval capability, we will attach a retrieval engine to the hierarchical index. The results of nearest neighbor retrieval applied to radiologic teaching files has been described by Bramble et al [3].

Case Library Description

The present Case Library consists of 200 cases and above 1,000 images presenting intracranial masses for skull X-ray, CT, MRI, and angiography. Images are stored on a CD-ROM. The Case Library helps the user reach a diagnosis by providing images from proven cases that match the description of a specific case being

evaluated along with the differential diagnosis list. The differential diagnosis list is formulated using rules embedded in the database that incorporate critical diagnostic cues for brain lesions (age of the patient and location of the lesion) and the judgment of neuroradiology experts regarding the probability of a given diagnosis. Based on the search criteria defined by the user, relevant images including a textual description are produced for comparison to the case in question. The user may browse through retrieved cases, zoom images, make a correlation between different procedures, or use the Quiz module for self-testing.

The screenshot shows a software window titled "Input Image". It contains several sections for data entry:

- Image number:** 5023.08
- Image order:** 4
- Exam date:** 7/23/91
- Age group:** Adult
- Procedure:** A list of radio buttons for Angiography, CT, MRI (selected), Nuclear medicine, Plain film, and Ultrasound. To the right are text boxes for View (Coronal), Contrast (Post-contrast), and Phase (T1 weighted).
- Image characteristics:**
 - Lesion location:** A text box containing "Skull and contents:Brain and meninges, supratentorial:Corpus callosum" with search and help icons.
 - Lesion characteristics:** Two text boxes containing "MRI Contrast enhancement:Pattern of enhancement:Heterogeneous" and "MRI Margins:Well defined:Butterfly lesion", each with search and help icons.
 - Associated findings:** A text box containing "MRI Edema:Present:Vasogenic" with search and help icons.
- Image caption:** A text box containing "Coronal T1 spin echo image after Gadolinium shows heterogeneously enhancing mass within the body of the corpus callosum." with search and help icons.

At the bottom right of the window are three icons: a document, a hand, and a left-pointing arrow.

Figure 2. Image Input screen presents fields for coding information that describes the image: procedure, lesion location following ACR code, lesion characteristics and associated findings following the *hierarchical image description vocabulary*, and image caption.

The Case Library was implemented in 4th Dimension™ (ACI US Inc., Cupertino, CA), relational database management system. To run the system, a Macintosh II model with 16 megabytes of RAM and a dual speed CD-ROM drive is the minimum recommendation. A 16" monitor is required. Any of the Macintosh II series computers with an 832 x 624 x 24bit color display graphics card may be used.

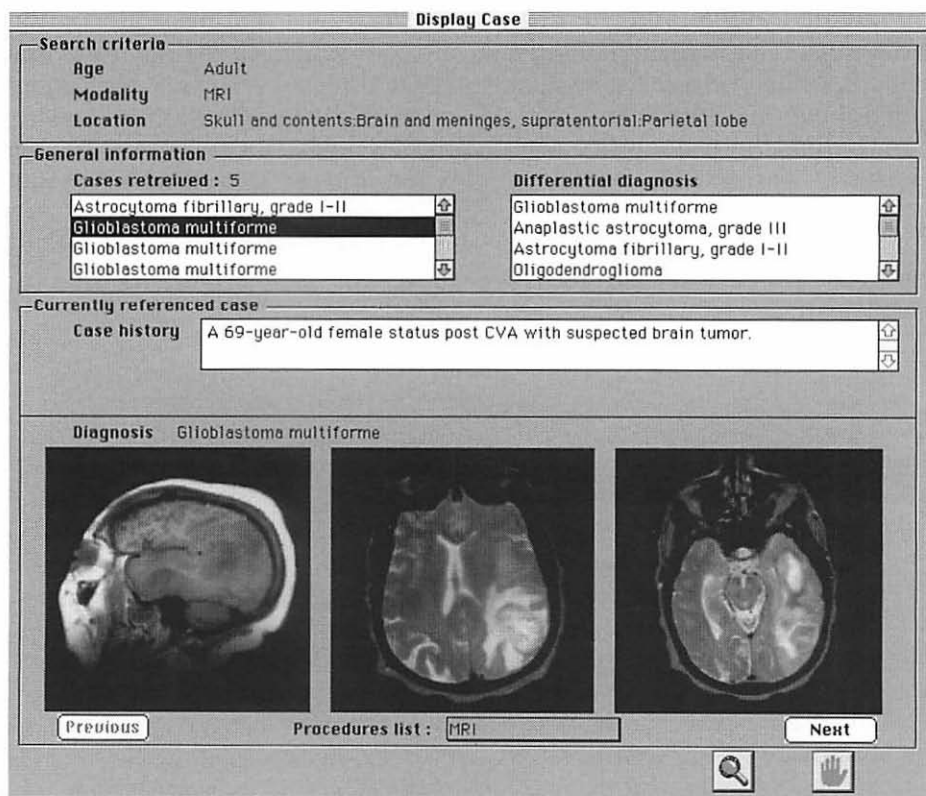


Figure 3. Display Case window. Based on the search criteria defined by the user relevant cases are retrieved along with the list of differential diagnosis. The user may browse through the cases, zoom images, access image captions, and change the procedure.

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Validation of Automatic Classification Strategies for the Measurement of Subcortical Hyperintensities on T₂-weighted Magnetic Resonance Images

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1 Introduction

A research project at Prince Henry Hospital involves investigation of the organic basis of late-onset schizophrenia. As part of the project, several brain measures involving MRI are being used. The investigators have been struck by the increased presence of hyperintensities on T₂-weighted images in the white matter and subcortical nuclei (basal ganglia and thalamus). These white matter hyperintensities (WMHs) exhibit a wide variety of size, shape, location and intensity. It is common to characterize them into four groups: ventricular caps, periventricular rims, focal WMHs and confluent WMHs. The pathological significance of these lesions is uncertain but we see it as important to determine the number, size and anatomical location of these lesions. We note that manual methods are time consuming and suffer from poor inter-rater reliability. We have looked for computer assistance as a way of obtaining reproducible results in a reasonable time.

A good automatic system would need minimal user interaction, would run efficiently on standard hardware and would be robust against the usual variations of patients and data quality. Mitchell et al [7] described a multilevel process to identify Multiple Sclerosis lesions in double echo MRI data sets. The process included an interactive cluster analysis step, refinement of lesion locations and a rule-based accept/reject step. Jernigan et al [5] described a semi-automatic process for the identification of WMHs in double echo MRI data sets. WMHs were identified by applying a pixel classification process on a per slice basis to the early and late echos, and an image formed from a linear combination of the two echos so as to optimize the contrast between CSF and brain. These studies reported they could not identify all hyperintense abnormalities but did not quantify the accuracy of the identification processes. Moreover, they did not indicate how the performance was affected by different classification algorithms.

We present the results of the evaluation of three supervised statistical classification algorithms and one unsupervised classification algorithm to estimate the number and volume of white matter hyperintensities. These classification strategies were evaluated for the ability to detect hyperintensities, to estimate the volume of hyperintensities, for classification stability with respect to training area selection and for speed of execution.

2 Statistical Classification to Segment Brain Tissues

Statistical classification strategies have been found to be effective for the identification of different brain tissue types [4, 6]. The statistical classification algorithms provide a way to construct a “feature space” (lookup table) to map from the pixel brightness values in multispectral images to the type of tissue. The dimensionality of the feature space depends on the number of images used in the classification. For double echo MRI, two images are used. The different tissue types give rise to “clusters” in the feature space. When the different tissues are well characterized by the pixel brightness values the clusters are well separated, but if the tissues have similar intensities then the clusters may overlap. For example, white matter and grey matter clusters usually overlap each other but not the CSF cluster.

Supervised classification algorithms make use of a training phase in which an operator selects training areas (“regions of interest”) for each type of tissue to distinguish. These regions are used to describe the range of pixel brightness values which characterize each tissue class.

All of these algorithms estimate the probability density function which describes the way in which the pixel brightness values of each tissue class varies. The estimated probability density function is then used to determine which class has the highest probability of occurring at each location in feature space. They can be distinguished by the way the training areas are used to characterize the tissue classes.

The maximum likelihood classifier [2] uses the assumption that the probability density function of the pixel brightness values for each tissue class is a Gaussian. This gives rise to a feature space in which the boundaries between different classes are given by hyperquadrics. The K Nearest Neighbour (KNN) [2] classifier makes no assumption about the shape of the clusters in feature space. The class for a given location in the feature space map is found by locating all the training area pixels in feature space and then selecting the class which occurs most often in the K nearest pixels. The Skidmore/Turner classifier [8] is a fast nonparametric classifier which works in a manner similar to the KNN classifier. The class for each location in feature space is that which occurs most often in the training area data at that location. When no training area data falls into a location in feature space no class can be assigned. To overcome this problem, the feature space is “collapsed” by rescaling the axes.

Unsupervised classification algorithms attempt to determine the feature space map without any training area data. These algorithms use the pixel brightness values directly and attempt to determine the “natural” clusters which are present. After the clusters have been found by the unsupervised classifier, the tissue type that each cluster represents must be determined - usually by an observer. ISODATA [1] is a well known unsupervised classification algorithm. It operates by first arbitrarily assigning clusters means. The pixels are then classified on the basis of which cluster mean they are closest to. The mean of each cluster is recomputed and the process is repeated until the clusters are stable.

3 Estimating Tissue Volumes from MRI

Computer based strategies for estimating the volume of brain tissues from MRI data must be designed to cope with imaging factors which affect the quality of the data. These include inhomogeneity in the magnetic field, system noise and the partial volume effect.

Magnetic field inhomogeneity leads to a smearing out of the clusters in feature space. When the clusters are well separated segmentation will not be affected [4, 6]. Anisotropic diffusion has been proposed as an effective technique for removing noise from MR images whilst preserving fine structures. Gerig et al [3] claim anisotropic diffusion is an important prerequisite for the segmentation of brain and CSF from MR data with minimal operator intervention.

The limited spatial resolution of MRI scanners gives rise to the partial volume effect, whereby pixels along the border between different tissue classes have a combined response from the tissue classes. The selection of training areas must be done in such a way as to avoid bias from this effect and the estimate of tissue volume should account for the possibility of a mixed response from some pixels. This may be particularly important for accurate estimation of the volume of small white matter hyperintensities.

4 Results

We compared the estimation of the number and volume of WMHIs as determined by manual analysis, supervised statistical classification and unsupervised statistical classification.

Ten patients with axial double echo MRI data of the whole brain, acquired on a GE 1.5T Signa scanner with slice thickness 5mm, interslice gap 2.5mm, TR 2100ms, TE 30ms/90ms, 1 NEX, 24cm FOV, 256x256 pixels per slice were selected from the group of patients participating in the study. Anisotropic diffusion was used to reduce noise in the data.

Manual analysis of the patients was performed by two observers. They studied the MRI data by displaying slices on a computer screen and determined the area of each WMHI by counting the number of pixels. The number, area and anatomical location of each WMHI in each slice was recorded. Figure 1 shows the number of WMHI determined for each patient, and figure 2 shows the volume of WMHI, measured in pixels. The results indicate the difficulty of the estimation task for both human observers and classification algorithms.

A scatterplot of pixels identified in the training phase as WMHI shows two separate clusters. One of these clusters represents "bright" WMHI, such as bright focal lesions and ventricular caps. These hyperintensities can be identified using statistical classification techniques [7, 5]. The second cluster substantially overlaps the clusters for grey matter and for white matter. WMHIs with pixel intensities in this cluster are difficult to distinguish from white matter and grey matter.

The MLC classifier describes the WMHI class by an elliptical region in feature space that encloses both the WMHI clusters and the region between them. This is an

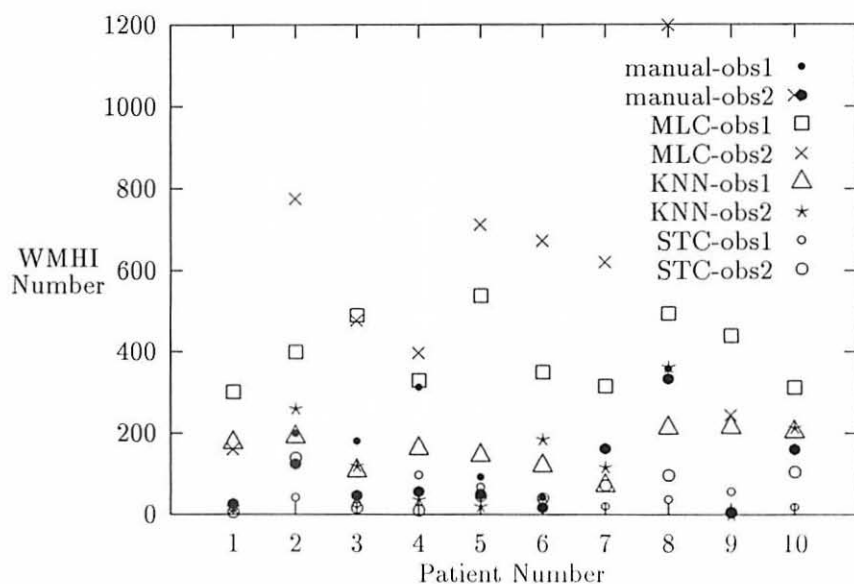


Figure 1: Estimates of number of WMHs

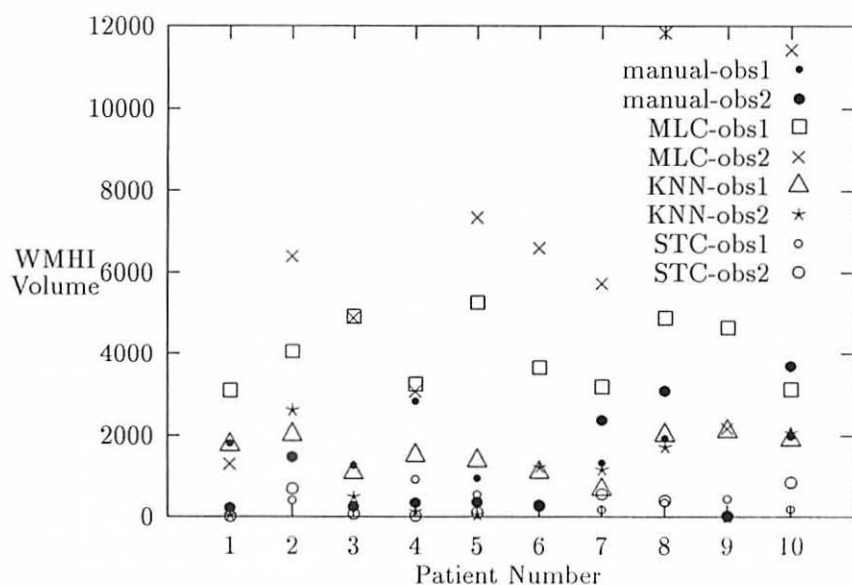


Figure 2: Estimates of volume (pixels) of WMHs

Patient	1	2	3	4	5	6	7	8	9	10
PVH	1	3	1	1	1	2	3	2	1	3
DWMH	0	2	1	1	1	2	3	2	1	2
SGM	0	1	1	0	1	1	2	2	0	2

Table 1: Qualitative assessment of severity of subcortical hyperintensities

inappropriate model for the data, and results in misclassification and overestimation. The KNN algorithm and the STC algorithm are able to identify two separate WMHI clusters. The KNN algorithm examines the neighbours of the location in feature space before deciding on the class, producing a slightly larger region than the STC algorithm which examines only the location in feature space to be classified. The STC makes a more conservative estimate than the KNN model but is more reliant on accurate training data.

A qualitative assessment of the severity of WMHIs in each patient was made so that classification performance could be compared across patients with a similar degree of WMHI. The severity of periventricular hyperintensities (PVH), deep white matter hyperintensities (DWMH) and hyperintensities in subcortical grey matter (SGM) was assessed on a scale from 0 (absent) to 3 (severe) and are presented in table 1.

The difference in execution speeds between the classification algorithms depends on how quickly the feature space is calculated. Each of the supervised classifiers operates by first calculating a lookup table for the brightness values, and then each pixel in the volume is classified from the map. The time to generate a classified volume includes the time necessary to apply the lookup table to each slice in the volume and to perform connected component labelling to extract the WMHIs from the classified image.

The time for the ISODATA algorithm to converge depends on the initial cluster centres and the size of the data set. Since the algorithm failed to identify a cluster (or clusters) for WMHIs we cannot report the execution time necessary to classify WMHIs using the ISODATA algorithm.

The speed to identify WMHIs with supervised statistical classification algorithms will vary from patient to patient since the size of the training area data will vary. The relative average speed of classifying one double echo slice was found to be 1:1:4.5 for MLC, STC and KNN classifiers respectively. The KNN algorithm required approximately 3 minutes real time to classify a slice on a Silicon Graphics Indigo Entry 4000.

The classification process would be much faster if training area data from one slice could be used to classify other slices, and other patients. The performance of the algorithms when trained by different observers indicates that the WMHI classification is sensitive to variations in training data selection. It was not possible to achieve satisfactory classification performance using training data from one slice to classify another and similarly the training data from one patient produced a poor classification when applied to another patient.

5 Conclusion

We have found that statistical classification algorithms cannot identify subcortical hyperintensities with the degree of accuracy we require. The unsupervised ISODATA algorithm failed to identify a separate cluster for WMHI at all.

In order to accurately identify subcortical hyperintensities we propose a semi-automatic analysis system which uses a training phase, a supervised classification algorithm and an operator supervised correction phase. The statistical classification algorithms perform well at identifying bright white matter hyperintensities, such as ventricular caps and bright focal hyperintensities, and the automatic area measurement we use removes much of the burden on the operator. However, some white matter hyperintensities have a pixel intensity in the same range as normal brain tissue. These cannot be resolved by a statistical classifier operating on pixel brightness values alone, so we allow the operator to correct the classification.

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Use of Lateral Surface Views of the Brain to Improve the Accuracy of Regional Localization within the Cortex

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Summary

In order to improve the accuracy of regional localization within the cortex, a facility to construct and display lateral surface views of the brain of a subject from his MRI study was developed. A regional contour outlined by the investigator on a surface view is automatically transformed to appear as a pair of markers demarcating the same region on the transverse MRI slices. These markers combined with the relative clarity of the grey-white interface in the images generally provide sufficient detail to perform accurate localization of cortical regions. The uncertainty in regional localization is considerably reduced because in most cases the various gyri and sulci of interest can be readily identified in the lateral views. In this way a template including regions of interest within cortex for each subject was created and used to match PET images of the same subject. A comparison between a method using the lateral surface view program and one that did not use it was made. The results indicate that data analysis based only on transverse MRI sections may be inadequate.

Introduction

PET images of brain have been widely used in clinical neurological studies. In order to perform data analysis of PET brain images, a template of regions of interest must be created ideally on the basis of MRI brain images of the same subject since functional regions and not anatomical structures of the brain are represented on PET images¹. Given a registered pair of MRI and PET studies of the same subject, region of interest (ROI) analysis of the PET images typically requires that the regions first be localized based on the anatomy apparent in the MRI images. Normally, this matching is performed on a slice by slice basis using only the transverse sections of the MRI study as a

reference. This procedure is prone to error especially when localizing structures of the cortex because of the inherent difficulty in identifying volumetric structures using only planar sections of the volume. In response to this difficulty, we used lateral surface views of the brain reconstructed from the transverse sections to outline each region on a surface view and to place markers identifying the same region on the transverse MRI slices.

Methods

MRI scans of twelve normal subjects were obtained. The number of slices in each study was 43 with 21 of T1 and 22 of T2 slices. Slices were 5 millimeters apart with the length, width and thickness of each pixel size being 0.86 millimeters. Each subject's MRI was resliced in the anterior commissure-posterior commissure (AC-PC) plane and the interval between slices was kept approximately the same as in the PET images. Then a lateral-view program² was used to create lateral surface views of each brain using the new MRI images resliced in AC-PC plane. The outlines of 12 cortical regions were drawn on the surface views and were automatically transformed to appear as markers demarcating the same region on the transverse MRI slices. Finally cortical regions were drawn on the transverse slices according to these markers. Subcortical and other regions were drawn based on the Talairach and Tournoux atlas³. In this way an individualized anatomic template was created and then applied to transverse PET images of the same subject resliced in the AC-PC plane.

We also created a "standard" template in which all the cortical, subcortical and other regions were drawn only based on the Talairach and Tournoux atlas without using information from the surface view of the MRI. This template was also applied to the PET images.

To illustrate the misplacement of regions by the method in which only the "standard" template was used, we compared the location of 24 cortical regions (12 on each side) in twelve MRI studies with the location of the same regions obtained when the lateral surface views of the brain were used. The location of each pair of corresponding regions was compared by measuring the distance between their centroids.

Results

A lateral surface view of the brain with region contours outlined is shown in Figure 1. Figure 2 shows pairs of markers demarcating the same region transformed onto the transverse MRI slice of the brain.

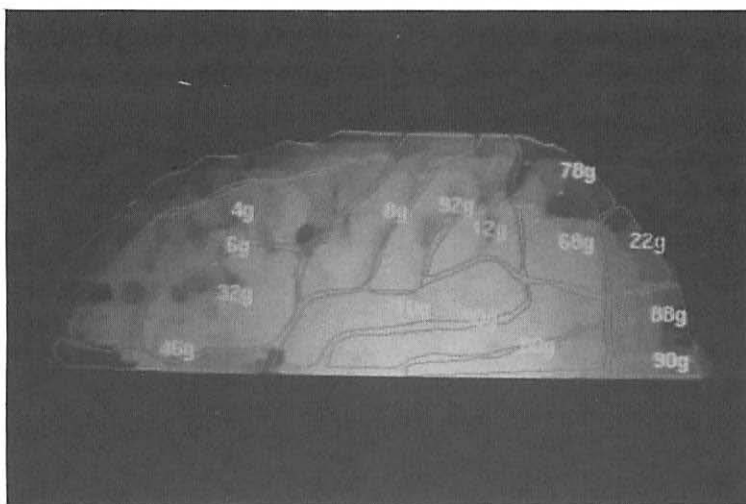


Figure 1. A lateral surface view of the brain with region contours outlined

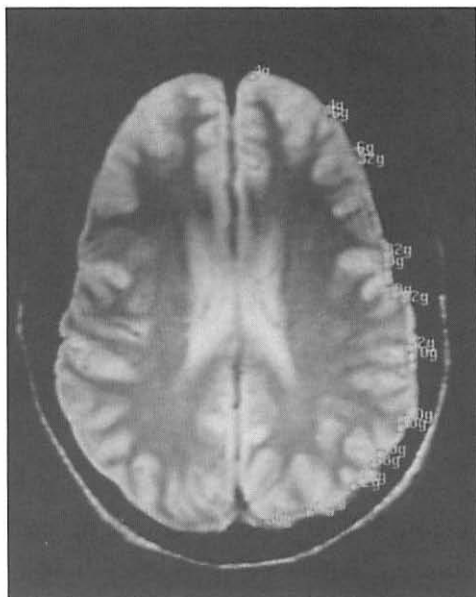


Figure 2. Transverse MRI slice with pairs of markers

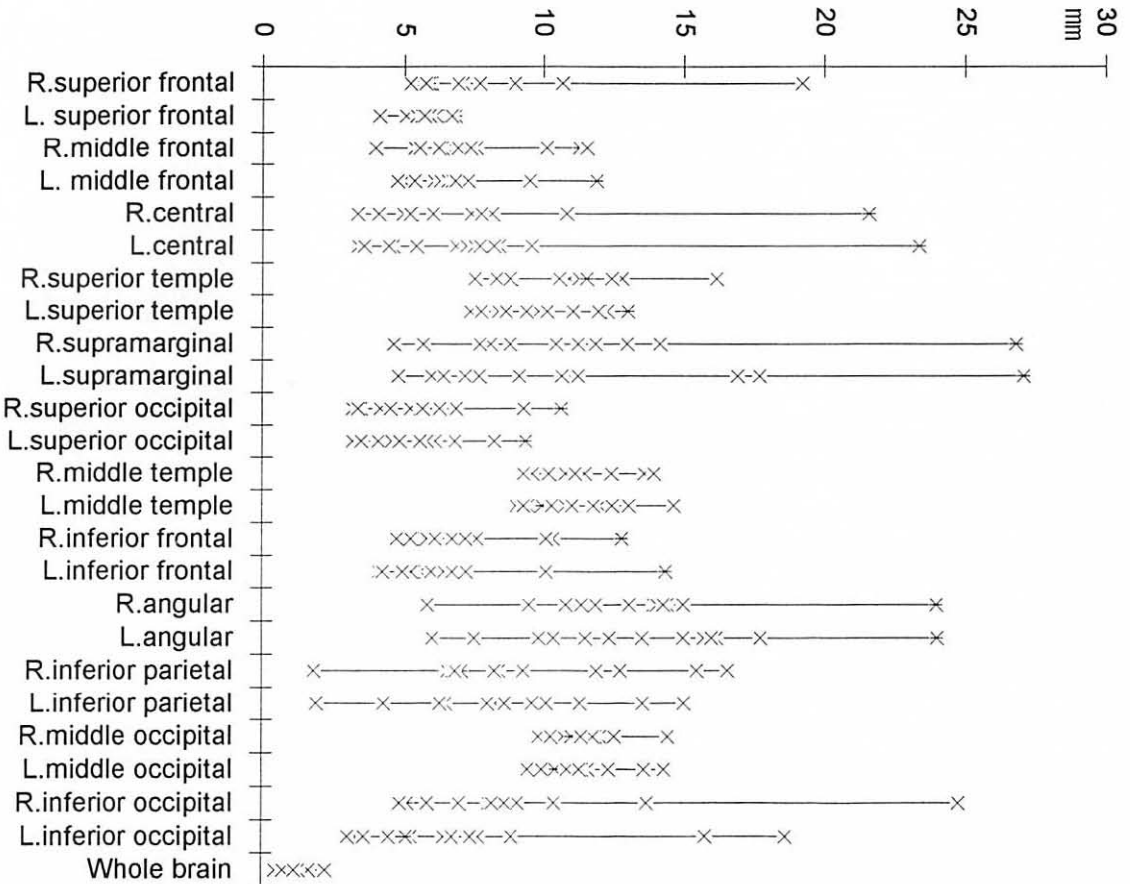


Figure 3. The distance between the centroids of each cortical region using the two different templates

For the 12 studies, the distance between the centroids of each cortical region using the two methods ranged from 1.9 to 27.1 millimeters (Figure 3), while the mean distances of the 24 cortical regions of the 12 subjects ranged from 5.6 to 13.5 millimeters, with the occipital gyrus being the minimum and the angular gyrus the maximum. The mean distance of the centroid of the whole brain for each subject which was used as a control region and should be zero theoretically, ranged from 0.5 to 2.3 millimeters with a mean distance for the 12 subjects of 1.2 millimeters.

The following formula was used in calculating the distance:

$$d = \{(X_i - X_s)^2 + (Y_i - Y_s)^2\}^{1/2}$$

X_i = number of pixels for the centroid's X axis coordinate for template using lateral surface view;

Y_i = number of pixels for the centroid's Y axis coordinate for template using lateral surface view;

X_s = number of pixels for the centroid's X axis coordinate for standard template;

Y_s = number of pixels for the centroid's Y axis coordinate for standard template.

Discussion

Use of a standard template based on a single brain may be attended by substantial anatomical functional mismatching on brain images of other subjects because of interindividual variation. Recently, studies of topographical variation of the human primary cortices were performed by J. Rademacher⁴ and a prominent variation was found. Our studies also revealed the mean distances of centroids of 10 cortical regions were over 10 millimeters between a standard template and an individualized one. Although these results reflect the inadequacy of only one investigator's interpretation of the cortical anatomy in transverse MRI images, it is not unreasonable to believe that similarly poor results will be obtained from other investigators performing the same task, especially since we have found that even subcortical localization within transverse MRI images can present difficulty to experienced radiologists⁵. These data suggest that interindividual variation can not be ignored and the approach of using a standard template in PET image analysis is not optimal.

When creating a template of regions of interest and localizing structures of the cortex on a transverse sections of a MRI image slice by slice, it's difficult to identify volumetric

structures and their border accurately by using only planar sections of the volume. The lateral surface view method we have developed can provide

markers which are automatically transferred from the surface view of brain to the transverse slices, thus demarcating the cortical regions. These markers combined with the relative clarity of the gray-white interface in the MRI images generally provide sufficient detail to allow accurate localization of cortical regions. The uncertainty in regional localization is significantly reduced because in most cases the various gyri and sulci of interest can be readily identified in the lateral views.

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SESSION 11

Artificial Intelligence

Chair: Robert T. Macura

Computer-aided Diagnosis of Acute Pulmonary Embolism Using Artificial Neural Networks

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I. INTRODUCTION

Acute pulmonary embolism (PE) is one of the most common cardiovascular diseases. Despite advances in diagnosis and prevention, mortality is still high and pulmonary embolism causes as many as 50,000 deaths per year¹. Since a significant number of pulmonary emboli go undetected, it is conceivable that prompt and accurate diagnosis is very important. Although pulmonary angiography continues to be the gold standard for the diagnosis of PE, ventilation-perfusion (V/Q) scanning is the initial study performed. Ventilation-perfusion scanning is noninvasive, safe, and well tolerated by the majority of the patients. However, there are limitations to its effectiveness for the diagnosis of PE. Perfusion abnormalities may have various causes, and the rules used for the diagnosis of PE have been the subject of controversy. Therefore, an improvement in the diagnostic yield of the current techniques could have major impact.

In this study, we present an artificial neural network (ANN) as a computer-aided diagnostic (CAD) tool for prediction of PE using only image findings from V/Q scans and chest radiographs. The findings and diagnoses used in the implementation of the network were extracted from the Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) database. The PIOPED study is the largest existing study on the significance of V/Q scans in the diagnosis of acute pulmonary embolism. It is the collaborative work of six medical centers with more than 1000 patients. The PIOPED database contains a detailed set of information - history, clinical findings, V/Q scans, chest radiographs - for 1493 eligible patients from the six participating medical centers. Furthermore, 1099 of these patients had a pulmonary angiogram

completed. Of these, 35 had angiograms with uncertain findings. Our study was based on the remaining 1064 patients who had certain angiograms. The network was evaluated using the Receiver Operating Characteristics (ROC) analysis and its performance was compared to that of the physicians participating in the PIOPED study. In addition, we tested the neural network on 104 new cases acquired at Duke University Medical Center to further evaluate its potential as a clinical diagnostic tool.

II. METHODS

The Neural Network Architecture

The neural network employed in our study had a three-layer, feed-forward architecture. Specifically, the network had an input layer with 21 nodes (each finding corresponded to an input node), a hidden layer with 15 nodes, and an output layer with a single, decision node. The network was trained using the backpropagation algorithm with the sigmoid activation function². According to this learning scheme the network tries to minimize the mean squared error (MSE) between the desired and the actual network output following an iterative gradient search technique. The network was trained to output 1 if PE was present and 0 if not. The weights were initialized between -1 and +1 and then they were adjusted each time a training pair was presented to the network. Also, the input data were scaled between 0 and 1. Both the learning and the momentum coefficients were selected 0.5. The neural network was implemented on a Stardent ST-1000 [Stardent Inc., Newton, Ma].

The PIOPED database

The PIOPED study investigated the significance of V/Q scans for the diagnosis of acute pulmonary embolism. A complete description of the PIOPED data collection and the results of the study can be found in reference 3. From all the available data, we selected the 1064 cases (383 positive, 681 negative) for which there was a definite angiographic outcome. For those cases, we extracted the physicians' interpretations of the V/Q scans, the chest radiographs, and the angiograms. Specifically, the 21 findings which comprised the input information for the network were the following. According to the PIOPED consensus reporting form, each lung was divided into three zones (upper, middle, and lower). From this reporting form entries,

we extracted three parameters for every lung zone (for a total of 18 findings). One described the chest radiograph, one the ventilation scan and, one the perfusion scan at the particular lung zone of interest. Each parameter was given a value between 0 and 5 based on the presence and the size of a possible defect [0 = normal, 1 = defect smaller than 25% of the lung zone, 2 = defect 25% - 50% of the lung zone, 3 = defect 50% - 75% of the lung zone, 4 = defect larger than 75% of the lung zone]. The other three input features were the following. First, we extracted the number of mismatched perfusion subsegments with possible values [0-36]. According to the protocol, a mismatched defect required that both the chest radiograph and the ventilation scan be normal in the region of the perfusion defect. Second, we included the ratio of the number of mismatched subsegments in the left lung (l_seg) over the number of mismatched subsegments in the right lung (r_seg) with values between 0 and 3 [0 if l_seg = r_seg=0, 1 if ratio < 1, 2 if ratio = 1, 3 if ratio > 1]. The final feature was the size of the largest effusion present in the chest radiograph [0=normal, 1=small, 2=medium, 3=large]. The angiographic outcome determined the desired output value [0=PE absent, 1=PE present]. In addition, the participating physicians had assigned a consensus percentage probability for PE derived from their own experience. This assigned probability was used to compare the diagnostic performance of the PIOPED physicians to that of the neural network.

Performance Evaluation

Successful application of a feed-forward neural network requires two steps: (i) the training phase where the network tries to learn the training examples, and (ii) the testing phase where the network is applied on new patterns different from those it was trained on. Generally, if a network has the proper architecture and sufficient training data it will be able to *generalize*; that is, to give the correct answer for patterns it has not seen during the learning phase. The PIOPED study provided us with a large number of well described clinical cases. First, we applied the network using the round-robin or jackknife method⁴. According to this method, all the database but one pattern (in our case 1063 examples) is used to train the network. Then, the trained network is tested on the pattern that is left out. The same process is repeated so that every pattern of the database is left out once. Obviously, this technique was very time-consuming because we had to train and test the network 1064 times.

However, the jackknife overcomes the problems associated with limited data. It uses the full potential of the available data for training without sacrificing the statistical significance of the testing phase. Second, we trained the network with all PIOPED cases and then we tested it on the 104 cases (19 positive, 85 negative) acquired at Duke University Medical Center. The 104 cases were reported using the PIOPED form and the participating physicians assigned a consensus probability assessment.

The results of our study are reported in the form of ROC curves. An ROC curve plots the true positive fraction (TPF) vs. the false positive fraction (FPF) for a continuous range of decision thresholds. We used the CLABROC algorithm developed by Metz *et al.*^{5,6} to fit ROC curves to both the network's and physicians' responses for every testing case. The CLABROC algorithm was employed for two reasons. First, it computes a maximum-likelihood estimate of the ROC curve based on *continuous* data such as the network's output data and the physicians' probability assessment. Second, it takes into account the case-sampling variation between the network and the human observers. The selected index of performance was the area (A_Z) under the ROC curves. Generally, a higher area index reflects better diagnostic performance

III. RESULTS

The following figures summarize the results of our study. Figure 1 shows the performance of the network after it was evaluated with the jackknife method on the PIOPED cases. The network significantly outperformed the physicians as this is indicated by the following ROC area indices:

$$A_Z(\text{net}) = 0.9121 \pm 0.0160$$

$$A_Z(\text{doc}) = 0.8172 \pm 0.0140$$

and this difference is statistically significant with a two-tailed p-value < 0.01 . Thus, the network was able to capture complex relationships underlying the image findings and it made a more efficient use of the V/Q scans.

Figure 2 shows the diagnostic performance of the network on the 104 Duke cases after it was trained with the PIOPED cases. In this case, the network performed as well as the physicians:

$$A_Z(\text{net}) = 0.7939 \pm 0.0688$$

$$A_Z(\text{doc}) = 0.8030 \pm 0.0622$$

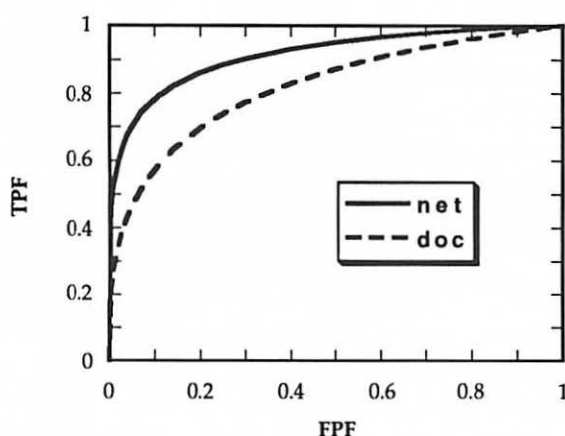


Figure 1: ROC curves comparing the diagnostic performance of the neural network (evaluated with the jackknife method) with that of the PIOPED physicians.

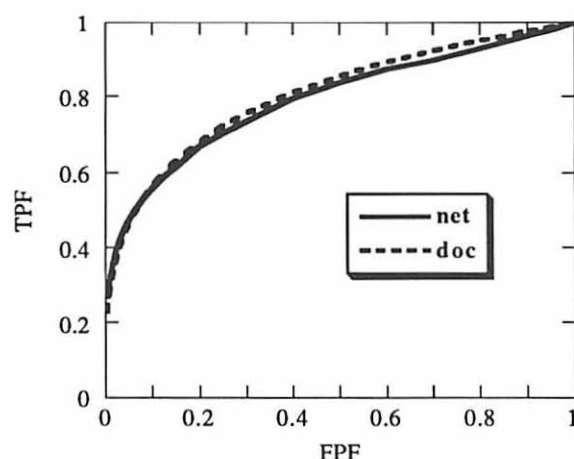


Figure 2: ROC curves comparing the diagnostic performance of the neural network (trained on the PIOPED cases and evaluated on the Duke cases) with that of the Duke physicians.

Although the network did not perform better than the physicians, this result is very encouraging since the Duke cases were different from the

PIOPED database. In the PIOPED study pulmonary angiograms were performed independently of the posttest likelihood of PE. However, the cases reviewed at Duke Medical Center represent a rather selective sample where angiography was felt to be essential for diagnosis. Furthermore, our network was compared to human observers with a vast experience in the interpretation of V/Q lung scans. Thus, we may say that our network was tested under very difficult circumstances.

IV. CONCLUSION

The purpose of our study was the implementation of an artificial neural network for the diagnosis of acute pulmonary embolism based only on findings from V/Q scans and chest radiographs. Our results show that a three-layer neural network can be trained to successfully perform the diagnostic task. Furthermore, our neural network could be developed as a computer-aided diagnostic tool to assist physicians in the diagnosis of PE.

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Computer Aided Image Diagnosis System for Chest Physicians—Lung Cancer Diagnosis

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I. INTRODUCTION

Recently, the incidence of lung cancer in Japan has been increasing, and it is now the most common type of cancer. Some medical laboratories have installed spiral CT devices and started studying the feasibility of detecting isolated small nodules by using them, in order to decrease the proportion of oversights. However, it is known that popularization of such devices and methods takes a long time. Therefore, a basic study of the detection of lung nodules in plain chest X-ray images is required in clinical situations. Some work on computerized detection of lung nodules in chest X-ray images has been published¹⁻³, but no system is in practical use by physicians. The primary problem in current systems is that they require computer environments that include a film digitizer, which are too expensive to configure as stand-alone systems. The second problem is the accuracy of the systems. Although most systems achieve a high level of sensitivity (over 80%), the specificity is lower (under 50%). Clinically, the required level of accuracy is over 80%; in particular, the specificity must be high.

Our proposed system, running on an IBM RS/6000 (a UNIX-based workstation), achieved scores of 85.2%, 73.3%, and 89.7% for the accuracy, sensitivity, and specificity, respectively⁴⁻⁷. We are conducting another study of how to distinguish malignant nodules from benign ones; this capability is essential for a practical system.

II. METHOD

The proposed system consists of seven sub-systems: image input, ROI extraction, nodule detection, rule-based false-positive elimination, statistical false-positive elimination, benign-malignant classification, and GUI for chest physicians. In the image input process, four types of input device can be connect to the system: a drum scanner, a laser film reader, NTSC video cameras, and a computed radiography. All the images input by each device are re-sampled to 350 x 350 pixels, and quantized to 256 gray levels (8bits/pixel); their resolution thus becomes 1 pixel/mm². The ROI extraction process defines the lung boundary and sets relational x-y coordinates for normalization to correct individual differences. The nodule detection process picks up a number of lung nodule candidates to increase the sensitivity of the system. The two false-positive elimination processes are effective in increasing the specificity of the system. The benign-malignant classification is to discriminate nodules that have been selected by the previous process. All of the sub-systems run on the X-window system under UNIX, and therefore most programs are portable to other UNIX-based workstations.

The algorithm and the logic for the nodule detection and the rule-based false-positive elimination are described below.

To detect lung nodules, we developed a directional contrast filter consisting of three concentric circles (Fig.1). In the figure, the radii of the three concentric circles are r , $3r$, and $5r$, respectively. The value of r depends on the sizes of the nodules to be detected; it is set at 3 mm in the system. The inner annular region is divided into eight equal segments, and the outer annular region is divided into sixteen equal segments. Each segment corresponds to a plurality of pixels, each having an image density value. The segments are located symmetrically relative to the origin O make a pair, and as a result the filter has directional characteristics. The feature value S for each pixel, with the origin O of the filter positioned over the center of the pixel, is calculated according to the following equation:

1. When $\text{Max}(W_B) < \text{Max}(W_X) < W_T$,

$$S = (W_T / \text{Max}(W_B)) - 1$$

2. In other cases,

$$S = 0$$

The terms W_T , W_X , and W_B in the respective segments denote the average image density values of the pixels located within a pair of corresponding segments. $\text{Max}(W_X)$ and $\text{Max}(W_B)$ represent the maximum values of W_X and W_B , respectively.

By using the previously described filter, the system automatically detects twenty foci of nodule candidates for each case, which include approximately nineteen false-positive foci. To eliminate these false-positive foci, we developed a rule-based method, which contains six rules that were heuristically developed according to a common method of diagnosis used by chest physicians. Physicians knowledge for diagnosis is complex and ambiguous; such knowledge must be transferred to definite rules. Our rules are shown in Fig.2 and may be expressed as follows:

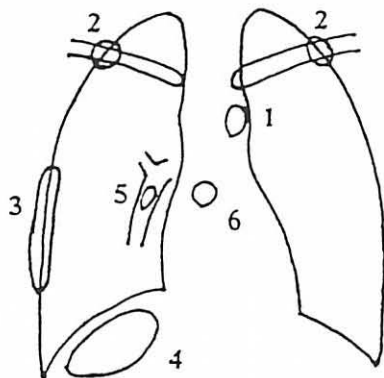
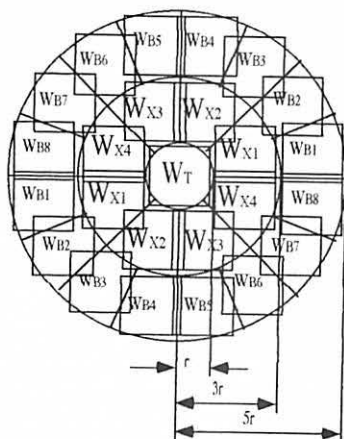


Fig.1 Directional Contrast Filter for Nodules

Fig.2 Rules (1~6) in the system

Rule-1 Eliminating aortic arch shadows

Rule-2 Eliminating symmetric bone shadows

Rule-3 Eliminating slender shaped shadows

Rule-4 Eliminating large shadows

Rule-5 Eliminating high-density edged shadows

Rule-6 Eliminating shadows in the mediastinum

These rules are then converted into lower-level knowledge and translated into a programming language and data by knowledge engineers, as follows:

Rule-1:

If{ $(X_C - 0.15)(Y_C - 0.4) < 0.15$ &
 $\text{Area}(C) > 100\text{mm}^2$ } Then Eliminate C

Rule-2:

If{ $|\text{Rank}(C_1) - \text{Rank}(C_2)| < 5$ &
 $|\text{Area}(C_1) - \text{Area}(C_2)| < 10\text{mm}^2$ &
 $|X_{C1} + X_{C2}| < 0.1$ &
 $|Y_{C1} - Y_{C2}| < 0.1$ } Then Eliminate C_1, C_2

Rule-3:

If{ $\text{MaxR}(C)/\text{MinR}(C) > 4$ &
 $\text{Area}(C) < 200\text{mm}^2$ } Then Eliminate C

Rule-4:

If{ $\text{Area}(C) > 500\text{mm}^2$ } Then Eliminate C

Rule-5:

If{ $\text{OverlayV}(C) > 0.95$ } Then Eliminate C

Rule-6:

If{ $Y_C < 4X_C + 1.0$ &
 $Y_C < -4X_C + 1.0$ } Then Eliminate C

C denotes a candidate. X_C and Y_C represent the values of relational X, Y coordinates for C. $\text{Area}(C)$, $\text{Rank}(C)$, $\text{MaxR}(C)$, $\text{MinR}(C)$, and $\text{OverlayV}(C)$ are functions for calculating the area of C, the ranking of C, the long diameter of C, the short diameter of C, and the proportion of the overlapped area between C and the vessel image extracted by the DCF-V (Directional Contrast Filter for Vessels), respectively. Though each threshold is experimentally fixed, the rules and thresholds can be modified by knowledge engineers.

III. EXPERIMENTS

To train the system, we collected 192 cases of lung cancer, each featuring a small nodule approximately 1 to 3 cm in diameter, and 74 normal control cases. We collected a further 30 cases of lung cancer and 78 normal control cases for evaluation, and 40 cases of lung cancer and 40 cases of benign nodules for discrimination. These cases were collected from all over Japan and sampled at random with a condition that is a small isolated nodule (Adenocarcinoma). Various image conditions were thus included in the data.

Each film was digitized by means of a laser scanner. The system takes about 1 minute from the time of scanning to classify a case as normal or abnormal. Currently, the benign-malignant classification sub-system is separate from the system.

IV. RESULTS

The accuracy of the DCF-N (Directional Contrast Filter for Nodules) is expressed by the proportion of true-positive results. For 192 training cases, 30 validation cases, and 40 classification cases of lung cancer, DCF-N obtained true-positive rates of 88.5%, 86.7%, and 87.5% for training cases, validation cases, and classification cases, respectively. In the 40 benign cases, the true-positive rate was 65.0%.

The effectiveness of the rule-based system is determined by the degree to which the false-positive foci are reduced without an increase in the false-negative rate. For the rule-based sub-system, the rates of decrease were 66.3% of false-positive foci with 5.0% of true-positive foci for the 192 training cases, and 68.3% of false-positive foci with 0% of true-positive foci for the 30 validation cases.

To compare the accuracy of the system with that of diagnosis by physicians, we did an interpretation experiment with 27 chest physicians, using the same X-ray films, and obtained figures of 82.1%, 79.7%, and 81.7% for the sensitivity, specificity, and accuracy of their interpretation. On the other hand, the system obtained figures of 73.3%, 89.7%, and 85.2% for the sensitivity, specificity, and accuracy, for the validation cases, as shown in Fig.3.

For benign-malignant classification, discriminant analysis was done by using six parameters that were calculated by an image measurement function of the sub-system. Each parameter showed a significant difference between benign and malignant nodule. As a result of the analysis, we obtained figures of 70.0% and 85.0% for benign classification and malignant classification, respectively.

	CANCER	NORMAL
POSITIVE	22 (73.3%)	8
NEGATIVE	8	70 (89.7%)
TOTAL	30	78

Sensitivity : 73.3%
 Specificity : 89.7%
 Accuracy : 85.2%

Fig.3 Result of the system

V. DISCUSSION AND CONCLUSION

The DCF-N, which was developed to detect nodule patterns with obscure peripheries, was evaluated as a high-quality noiseproof filter by an examination using various actual cancer shadows. The primary reason for the progress is that we designed the filter to embody the knowledge of expert physicians. The detection process is the key technology in the system.

In the processes for eliminating false-positive foci, the rule-based sub-system was effective in eliminating false-positive foci without significantly increasing the number of false-negatives. The rules employed in the rule-base were developed to be universal for both physicians and the system. Therefore, the rule-base method is not influenced by image quality.

We found six significant differences between benign and malignant shadows. In particular, the parameters for measuring their density slopes contribute to the distinguishability of such shadows. These results are useful for classifying nodules in discriminative diagnosis using a computer-aided system.

The total accuracy of the system was almost equal to that of physicians in the interpretation experiment. In a detailed comparison, 75% of the false-negative cases detected by the physicians were detected as true-positives by the system. Thus the system can support physicians in double-checking by showing cases that it detects as true-positive.

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Model-Based Interpretation of Chest X-Rays

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Abstract

An "expert assistant" system has been designed to recognise basic anatomical features in anterior-posterior X-ray views of the chest. The long-term aim is to develop a model-based interpretation methodology which may be applied to other imaging modalities and anatomical regions. Key features of this methodology include a three-dimensional anatomical model, an inference engine, image-analysis and visualisation tools and an overlying control structure. The anatomical model is object-centred, incorporating shape and connectivity information, and is designed to accommodate normal and disease-related variations. The inference engine incorporates into its model previously located structures for the identification of further structures. A preliminary version has been implemented using frame- and blackboard-based architecture.

1. Motivation and Goals

The Medical Image Understanding (MIU) project aims to provide "expert assistance" for radiologists in the context of high-throughput, digitally based Radiology Departments. This is achieved through model-based automatic analysis of images to provide "alerts" for abnormalities [1] and decision support for equivocal diagnoses [2]. An important design criterion for such a system is the ability to incorporate heterogeneous information sources, such as images formed from different imaging modalities and non-imaging sources. Simple image registration is not possible for many imaging modalities, for example, if a diagnosis is to be performed using images made by projection (such as X-rays) and sectioning (such as ultrasound). In this case both the image-formation physics and the image geometry make direct image comparison impossible. Another aim of this project is to explore image-understanding algorithms which may be applied to different anatomical regions. Many of these aims are achieved by basing image analysis on separable models of anatomical structure and image formation, and by performing data fusion in the domain of actual anatomy.

Many of the ideas inherent in the Medical Image Understanding concept are being incorporated in a demonstration project restricted to one anatomical region and, initially, to one imaging modality. Chest X-rays have been chosen for this initial study, because they represent a common diagnostic problem where expert assistance might improve diagnostic accuracy, and the projection imaging technique requires a complete anatomical model for image interpretation.

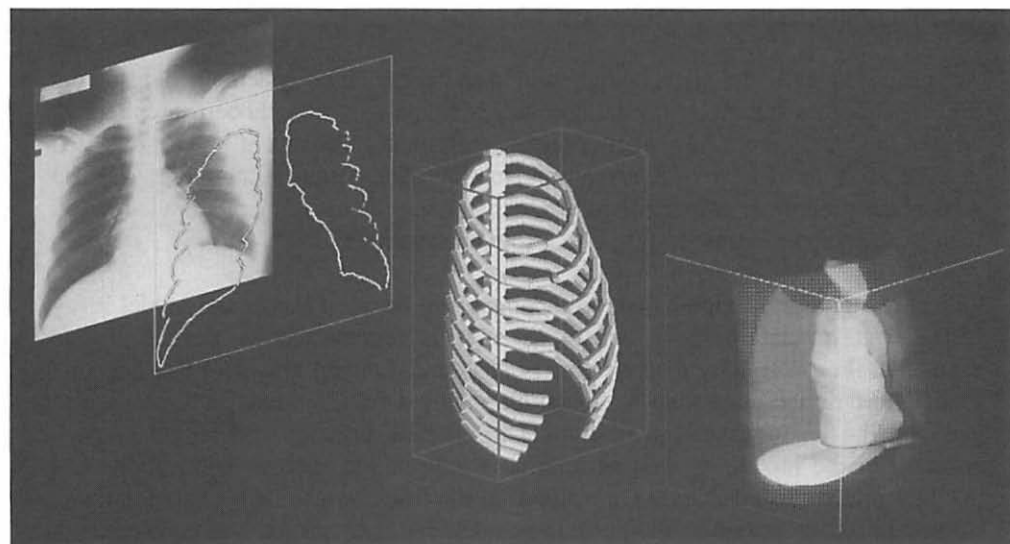


Fig. 1: Examples of the principal elements of the Medical Image Understanding chest X-ray analysis system. Left to right: original X-ray image; derived features of the image, in this case lung outlines; visualisation of a 5-parameter model of the skeleton fitted to the X-ray image; visualisation of a soft-tissue model including pleurae, diaphragm and mediastinum.

2. Methodology

The central feature of the MIU methodology is an object-centred, three-dimensional, deformable description of human anatomy, since the anatomical model is thought to be the paradigm for expert analysis of medical images. This description assists in (a) guiding image segmentation by predicting features based on current instance information [3] [4], (b) checking for abnormalities and (c) visualising the resulting instantiated anatomy. The model is sufficiently explicit to permit precise prediction of features such as the edges of specific organs. The interaction between image and model is via a feature space:



"Anatomical space" refers to a description of anatomy, both normal and abnormal, which may be varied to maximise the fit between model and image(s). Image space is the pixel space, which may include multiple image modalities. Feature space includes symbolic descriptions of image features (such as edges and textures) derived from model and image space.

3. Preliminary Experimental System

The proposed methodology is being tested in an experimental system developed on a Silicon Graphics Indigo2 workstation using a frame-based blackboard architecture written in C and Lisp. This paper describes preliminary analysis of images digitised to 8 bits and up to 1K by 1K resolution from anterior-posterior chest X-rays. The goal of the preliminary system is to locate features using anatomical knowledge and then perform some simple tests to check for abnormalities.

Object recognition is edge-based, with comparison between image and model being carried out in feature space, where an edge is represented by connected line segments. For simplicity the preliminary anatomical model also uses line segment models to describe edge shapes, though ultimately a full 3D model will be used to generate the feature-space elements. The expected direction and length of each segment in the model, as well as relational information such as connections and position relative to other edges, are stored in the frame system [5]. This relational information is described explicitly in the model, and is translated into constraints in the feature space.

3.1. Control Architecture

The control architecture uses a blackboard [6] to store the contents of the feature space. The blackboard consists of two types of frames:

1. Model frames, each containing a line segment translated from an edge in the model into the feature space. Intrinsic and relational knowledge about the edge are translated into constraints on the position, length and orientation of the corresponding line segment.
2. Instance frames, each containing pixel coordinates which are candidates to be matched to a given line segment, i.e. they are instances of the edges predicted by the model.

The blackboard also contains the instances which are currently considered to be the best match to the model. Each instance frame has a confidence score based on how well it satisfies the constraints given by its model frame.

3.2. Major Landmarking

To provide initial guidance to the segmentation, some major landmarks are identified first. The midline is found using a symmetry-detection algorithm [7]. The approximate boundaries of the body, lungs and ribs are then found using a variety of segmentation techniques, such as seeded region growing [8] and thresholding [9].

Since the edges in the image are inter-related, new edges found with high enough confidence are used to update relational constraints on other frames. Backtracking is likely to introduce convergence problems and be computationally intensive, and so it is limited by grouping mutually dependent edges, such as connected edges, and permitting backtracking within, but not between, groups.

To recognise a group of edges, the first step is to perform edge detection on the image to create a set of candidate edges (instance frames) for each model frame. Combinations of the candidates can be examined using backtracking to find the set which yields the highest confidence. There are two elements to the strategy for finding groups:

1. Careful choice of the order in which the groups are found. Groups which are independent of others, and those for which the related groups have already been found, are generally processed first.
2. When imposing constraints on a group via its relationship to another group, attention is paid to the confidence with which that other group was found.

After matching the line-segment model to the image, actual pixel boundaries can be located by performing local edge detection near the line segments.

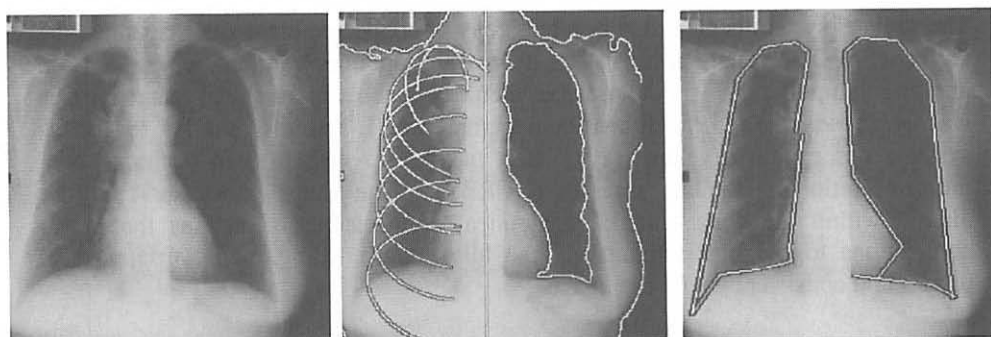


Fig. 2: Initial landmarking and fitting of line-segment model. Left to right: original X-ray image; midline and initial rib and lung landmarking; line-segment model fitted to lung, diaphragmatic and mediastinal borders.

The above strategy is used for landmarking lungs, mediastinum and diaphragm. An important feature of chest radiographs is the depiction of ribs, and our project aims to identify each rib using an explicit anatomical model. This will be used for fixing parameters in the 3D anatomical model. Several techniques have been investigated for identifying ribs in these images. For identification of incorrect patient positioning it is necessary to match images of anterior and posterior rib segments. This is done by fitting curved segments to the intersections of the rib images with the lateral margins of the lungs, the continuity of the rib image providing the information which links the anterior and posterior rib segments. A full, 3D rib model now under development will permit more complete identification of skeletal structures, and information on patient positioning. This skeletal model, together with major soft-tissue landmarks, will assist in locating more subtle image features.

3.3 Three-dimensional Model

The requirements of the model are served through an object-centred anatomical description being developed in parallel with the image processing and control structures. Anatomical descriptions are incorporated into the frame structure used in the image analysis system described above. Information stored in the slots for each organ, or part of an organ, includes location in a prototype anatomy, shape descriptors, inherited parameters, imaging properties (e.g. X-ray density), connections to other organs and adjacency relationships.

Slightly different descriptors are used for the skeletal system and soft organs, because of the different constraints imposed upon them. The parameters of the skeletal system are determined directly from the image, and are not subject to a space-filling constraint. However, soft-organ size and shape are partly determined by space-filling and adjacency constraints, i.e. all internal body spaces are filled, but no two organs can occupy the same volume.

The skeletal system is modelled as a hierarchy of connected elements, starting at the C7 vertebra. Each element consists of a rib, rib segment or vertebra, whose location and orientation depends on the previous element. Such a hierarchical representation was achieved using three-dimensional parametric, L-systems, similar to the L-systems description of plants [10]. Soft tissues are described in terms of non-uniform, rational, B-spline surfaces (NURBS). The shape parameters may be altered within the constraints of anatomical connectedness (such as the lungs-connections to the mediastinum via the hila), space filling, non-overlapping of organs and consistency with the image.

The symbolic linkages inherent in the object-oriented structure of the anatomical model permit consistent variation of model parameters to fit images, or simulated effects of specific diseases, while its explicit 3D structure facilitates generation of feature-space information (such as the location of a given edge) which may be compared directly with corresponding features derived from image space.

4. Conclusions and Future Work

Image-processing techniques have been successfully demonstrated for segmenting chest X-ray images, using mainly two-dimensional models for identifying lung outlines and ribs. A frame- and blackboard-based control structure has been created for high-level control of the segmentation and linking to higher level descriptions. A three-dimensional anatomical model has been constructed and is being linked to the image-processing modules via the frame structure, and this will provide guidance for the detailed segmentation of the X-ray images. A logical extension of the project is to include both lateral and anterior-posterior views, which can be compared readily in anatomical space. Because of the anatomical nature of the prior knowledge, the clinical emphasis of the project is on diseases producing structural rather than disseminated or focal change, and on diagnosis based on edge location and characteristics, rather than textural analysis.

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Performance Assessment of Hybrid Lung Nodule Detection System

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ABSTRACT

This paper describes a Computer Aided Diagnosis (CAD) system to improve the accuracy and speed of object recognition in cluttered and noisy image background. The detection method is based on a hybrid scheme of digital processing, artificial neural network and knowledge base synergy. This CAD tool was applied to early detection of cancerous pulmonary nodule from X-ray films. The resulting hybrid system is a robust, effective and fast Hybrid Lung Nodule Detection (HLND) System. The system architecture and performance assessments are also reported.

INTRODUCTION

Despite the vast improvements in digital computer technology in the past few years, differentiation between the object of interest and the image background which contains similar attributes as the object of interest (e.g., true-positive and false-positive of nodules from radiography) still remains a challenging problem. Artificial neural network (ANN) techniques are chosen for this class of problems because of its capability to learn and generalize from training data set. A Computer Aided Diagnosis (CAD) system to improve the accuracy and speed of detection and classification of lung cancerous pulmonary radiology is developed[2,17,18]. As shown in Figure 1, the configuration of the Hybrid Lung Nodule Detection (HLND) system includes the following processing phases: (1) pre-processing to enhance the figure-background contrast; (2) Morphology based quick selection of nodule suspects based upon the most prominent feature of nodules; and (3) feature space determination and neural network based suspect fields reduction; (4) neural network based knowledge fusion processing and final classification of suspect fields.

Hybrid Lung Nodule Detection (HLND) system is developed to integrate the robustness of ANNs and the logic reasoning of knowledge bases with the accuracy of digital signal/image processing techniques in a single system for shape feature analysis in diagnostic radiology which provides accurate and robust recognition performance.

Doi and Giger of University of Chicago have shown that it is feasible to automate the lung nodule detection process by searching in the chest X-ray radiography for a set of preselected nodule features [1,3-7].

median filter) from a nodule enhanced image (through a matched filter with a spherical profile) [2-7]. This approach would reduce the camouflaging anatomic background in the radiograph thereby enhance the signal to background ratio. The difference image, containing nodule-enhanced signal, is used for morphology base selection processing phase.

A search algorithm is applied for quick (pre-) selection of all possible nodule suspects based mainly upon the most prominent feature of nodule - the spherical profile [4-6]. The difference image is processed by locally-adaptively area extraction process using edge and gray value tracking with different gray values for thresholding and morphological operations. It provides an initial determination of features, arising from nodules and arising from anatomic background. Circularity and effective radius of the segmented image block are evaluated at different thresholding levels to determine the location and the size of the nodule suspects. All the suspect areas (blocks) with dense area (high gray values) equivalent to 3 mm of diameter or less are captured in 32x32x12 bits images for further evaluation.

FEATURE DETERMINATION

Since the quick selection process are based on the general features of lung nodules -- the spherical profile, a classification algorithm based on localized anatomic features is needed. We developed an algorithms for localized feature extraction and classification based on gradient edge analysis of local anatomic structure in the 32x32 image blocks [2,15-18].

After first two processing phases (pre-processing and morphology based quick selection), nodule suspect A-Fields are determined from each image. The nodule suspect is extracted into a 32x32 pixel image (larger than 9 mm in diameter) sufficient for the ANN-based development. After processing 31 radiographs, 457 nodule suspects in original and difference image blocks (32x32 pixel) are obtained for further development of the ANN classification. The following table shows the distribution of true-positive and false-positive nodule suspects.

bone	endvssl	rbvsxng	ribedge	ribxing	vessel	vsclust	unknow	true
42	43	40	30	96	15	41	54	96
9.19%	9.41%	8.75%	6.56%	21%	3.28%	8.97%	11.82%	21%

The suspect image blocks are first classified into 8 classes: true nodule (true), rib crossing (ribxing), rib-vessel crossing (rbvsxng), vessel cluster (vsclust), end-vessel (endvssl), rib edge (ribedge), bone (bone), vessel, and unknow structures based on the content of the image and previous related works [2, 11]. Generally, the suspect image blocks contains more than one class of information. Since eight (8) categories of anatomic classes are obtained from real radiographs, overlapping of several phenomenon in single image block is quite common. The classification is primarily based on the most dominant anatomic structure in the image. Based on these image blocks, several features are analyzed and extracted.

Since the morphology search process are based on the general features of lung nodules, the resulting suspect A-fields images will have some kind of similarity within them. Thus, a feature extraction method that defines a feature space in which the ANN architecture can easily converges to a decision surfaces to separate the suspect A-fields into clusters representing different classes of anatomic structures. In other word, a feature extraction function that can complement the morphology filter function is desired. Such feature extraction algorithm should reduce the similarity features arise from morphology search algorithm, yet focus on the complementing features.

In the case of lung nodule detection's pre-processing phase, a median filter was used to suppress the object (lung nodule) image. However, the median filter also has the effect of smoothing the image and suppress the image noise. In the feature extracting phase, we can reduce the effect of noise by smoothing the image before applying the operator or we can use an operator that compute the differences of local averages.

However, an operator based on differences of averages will respond blurrily (weakened) to edges that are not optimally oriented. Therefore, a weighted averages can be used to sharpen the response to less than optimally oriented (0° and 90°) edges. The operator we choose to use in this case is:

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

These operators (called *Sobel operators*) gives greater weight to points lying closer to (x,y), thus its response to diagonal edges is not weakened as much as the previous operators.

A 3x3 Sobel operator are defined for image edge enhancement. The Sobel operator is applied to the suspect image A-fields to obtained two sets of gradient images: one is differential amplitude image (amplitude) and another one is amplitude orientation image (orientation).

By performing the histogram operation on gradient image, two sets of marginal distribution curves are obtained: one for orientation distribution and another one for amplitude distribution. Feature vector pairs are generated from histogram of marginal distribution curves (histogramic sobel reponse). The histogramic sobel reponse produced identifiable features in amplitude and orientation gradient image.

ANN CLASSIFICATION

A supervised back-propagation (BP) neural network classifier is developed for classification of each anatomic structure. The BP ANN classifier contains four layers with three layers of trainable weights. Input layer consists of 64 neurons

corresponding to combination of both amplitude and orientation bins of marginal distribution. Two hidden layers contains 128 and 64 neurons, which are chosen as multiple of eight (pre-determined anatomic structure classes) since the properties of each class are desired to be coded evenly within the network. Finally a two-neuron output layer is used to classify either true positive or false positive nodules.

EXPERIMENTAL RESULTS

It takes around 130 epoches to train the BP ANN classifier to learn up to 100% accuracy of the training data set. With a fully-trained BP ANN, True-positive classification accuracy can reach 91.5% over the overall image base as shown in the following table. It is found that the trained BP ANN increases the detection accuracy of true nodule up to 91.5% with around 8.5% false detection.

class	Samples	Correct	Error	Correct %	Error%	Samp/ Film	Correct /Films	Err/Film
bone	42	41	1	97.62%	2.38%	1.35	1.32	0.03
endvssl	43	37	6	86.05%	13.95%	1.39	1.19	0.19
rbvsnxg	40	37	3	92.50%	7.50%	1.29	1.19	0.10
ribege	30	28	2	93.33%	6.67%	0.97	0.90	0.06
ribxing	96	87	9	90.63%	9.38%	3.10	2.81	0.29
vessel	15	13	2	86.67%	13.33%	0.48	0.42	0.06
vsclust	41	39	2	95.12%	4.88%	1.32	1.26	0.06
unknow	54	49	5	90.74%	9.26%	1.74	1.58	0.16
true	96	87	9	90.63%	9.38%	3.10	2.81	0.29
total	457	418	39	91.47%	8.53%	14.74	13.48	1.26

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Application of Case-Based Reasoning to the Selection of Diagnostic Imaging Procedures

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Case-based reasoning (CBR) is an approach to computer-based cognition that involves learning and reasoning from prior experiences: new problems are solved by recalling and adapting solutions that were used to solve old problems [1,2]. A CBR system's knowledge base, or "memory," consists of cases indexed by their pertinent features. Its dynamic operation involves encoding new cases and storing them into memory, activating (retrieving) cases from memory that are pertinent to the current situation, and adapting the actions of retrieved cases to compute a course of action for the current situation. Case-based reasoning has been applied experimentally in medicine to clinical audiology [3,4], diagnosis of heart failure [5], and planning of radiation therapy protocols [6].

ISIS (Intelligent Selection of Imaging Studies) is a case-based decision support tool being developed to help physicians select appropriate radiologic procedures [7,8]. It provides computer-based expertise in the domain of diagnostic imaging procedures such as computed tomography (CT), ultrasound (US), and magnetic resonance imaging (MRI). A prototype version of ISIS, called ProtoISIS, was developed based on Protos, a program that performs case-based classification. Protos learns to classify cases based on associations between categories and exemplary cases ("exemplars") [3,4]. Protos attempts to classify a new case by matching it to cases with similar features. We implemented CL-Protos, a version of Protos in the Common Lisp language [9], in Macintosh Common Lisp 2.0 on Macintosh IIsx and PowerBook 180 computers (Apple Computers, Cupertino, Calif.).

An "exemplar" is a case that particularly represents the specified category. Each exemplar in Protos consists of a name, a set of features and a classification. Each term known to the system may have an abbreviation and one or more synonyms. This information is supplemented by

explanations that relate two or more terms. When a new case is presented, Protos gives the user the choice to pre-classify the case or to let Protos suggest a classification. If no suitable case is found, Protos asks the user to classify the case and to provide an explanation that relates the features of the case to the specified category.

ProtoISIS was trained with 200 consecutive cases of actual body CT and ultrasound requests from one week of radiology department records. After learning these cases, ProtoISIS incorporated a total vocabulary of 527 terms: 200 training-case names, 29 imaging procedures, 37 abbreviations, 40 synonyms, and 220 features of cases. To test the system, 100 new, consecutive ultrasound and body CT cases, grouped into four sets of 25 cases each, were presented sequentially. After each case's identifier and clinical features were entered, ProtoISIS attempted to assign the correct category to each case. If ProtoISIS was unable to assign a category or assigned an incorrect category to a case, we added that case and pertinent explanations into memory. ProtoISIS incorporated into its knowledge base all new terms — such as abbreviations, synonyms, and features — that were encountered in the test cases whether or not the case to which they belonged was itself added.

Overall, ProtoISIS correctly classified 72% of the imaging-procedure requests on the first attempt. Its performance improved as it gained experience: in the last two test series, it correctly classified 84% of the cases presented, compared with only 56% in the first series. Such improvement is typical of case-based learning. In many of the incorrectly classified cases, the correct imaging procedure received the second highest matching score. Only three test cases required new imaging-procedure categories. On average, 40% of cases included terms that had not been encountered previously; given the small number of training cases, the large vocabulary of medicine, and the variety of ways that a single medical concept can be expressed, this finding is not surprising.

ISIS builds on the framework of ProtoISIS and incorporates two additional properties to overcome the prototype's deficiencies. First, ISIS distinguishes between known features (patient history) and those being queried (clinical questions). Second, ISIS treats imaging procedures as elements of a plan, rather than as categories. ISIS can modify a plan's components instead of creating a unique category for each imaging protocol. This approach facilitates proper sequencing of imaging procedures and offers much richer interaction between computer and

physician. In addition to the procedure requested and the clinical information provided, each case includes information about the procedure actually performed and the imaging technique or protocol. Each case includes clinical questions to be asked of the referring physician to determine the appropriateness of the requested imaging procedure and to assist the radiologist in formulating a diagnosis.

Existing decision support systems for radiologic procedure selection include rule-based systems [10,11], hypertexts [12,13], and belief networks [14]. Our work with ProtoISIS demonstrates that case-based reasoning can be applied successfully to the selection of diagnostic imaging procedures. The use of CBR techniques permits rapid development and testing of medical decision support systems that will allow continued revision as new cases are presented to the system.

Once ISIS has been completed and validated, it will be integrated with our department's clinical information system, where it will provide interactive, on-line expertise to physicians at all times of the day, and be available to physicians in their work areas, such as clinics, inpatient wards, intensive-care units and the emergency department. Such a system will have excellent potential to significantly improve the quality and cost-effectiveness of medical care, and will offer an opportunity to study the role of case-based reasoning in day-to-day medical decision making.

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Machine Learning for Radiological Image Retrieval Knowledge

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1 Introduction

A Picture Archiving and Communications System (PACS) provides a totally digitized system for acquiring, storing, managing, transmitting, retrieving, and presenting radiological images and relevant patient/examination information for supporting radiology services. However, the adoption of a PACS cannot succeed without a re-engineered service delivery process and embedded value-added intelligent information analysis and retrieval support to get around the problem of performance bottlenecks in large-scale information system applications.

Our research has developed an Image Retrieval Expert System (IRES) which embeds radiologists' knowledge of determining the relevance between prior examinations and the current examination to retrieve relevant prior examination images that can be used to confirm initial suspicions and/or to evaluate disease progression during primary reading [5, 6, 7, 11]. One of the key issues in developing IRES knowledge-base (KB) is the acquisition of radiologists' image retrieval knowledge. The traditional knowledge acquisition approach which involves a series of interviews/interactions with radiologists to acquire knowledge has been used in the IRES development [5]. However, using this approach, the development of IRES KB was constrained by such bottlenecks as radiologists' difficulty to articulate image retrieval knowledge and the variation in image retrieval knowledge among radiologists. In addition, the lengthy process of interviews renders it uneconomic to maintain the IRES KB at a level of closely resembling up-to-date radiologists' image retrieval behavior.

To overcome these bottlenecks of the IRES KB development resulted from the traditional knowledge acquisition technique, a potential alternative technique—inductive machine learning—was explored. Inductive machine learning facilitates knowledge acquisition and maintenance through the induction of knowledge embedded in example radiological image reading cases.

The remainder of the paper is organized as follows. The research framework is depicted in Section 2. In Section 3, the problem analysis and the selection

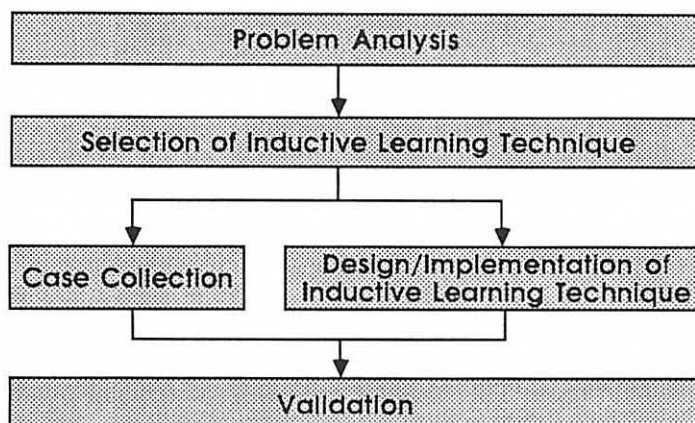


Figure 1: Research Framework

of a desired inductive learning technique for image retrieval knowledge are discussed. The design and implementation details of the selected inductive learning technique as well as the case collection process are described in Section 4, followed by a summary of the validation of image retrieval knowledge induced by the learning technique in Section 5. The paper is concluded in Section 6 with a summary and a discussion of future research.

2 Research Framework

Inductive learning induces knowledge from training examples, each of which can be described by a set of characteristics (i.e., input attributes) and the decision result of the example. The validity of the induced knowledge depends on the learnability of inductive learning technique used, the selection of attributes, and the quality of training examples [2]. A research framework, as shown in Figure 1, is proposed to improve the validity of induced knowledge.

Problem Analysis: Problem analysis, requiring cooperation between experts and knowledge engineers, involves 1) the identification of problem domain of interest and 2) the analysis of input attributes which impact decision making, the decision making patterns (i.e., output classes), the characteristics of the problem domain, etc.

Selection of Inductive Learning Technique: The most frequently used inductive techniques are symbolic learning algorithms (e.g., ID3 [9]) and neuro-network learning techniques (e.g., Backpropagation network [10]). The ID3 algorithm has such strengths as understandable learning results and requiring

no parameter tuning as compared to the Backpropagation network technique, which is superior in noise resistance and fault tolerance. The characteristics of the problem domain will be used to facilitate the selection of the most desired inductive learning technique.

Cases Collection: Cases will be used as training examples for the selected inductive learning technique and testing examples during the validation phase. As mentioned, the quality of examples will affect the validity of induced knowledge. The quality of examples can be best described as "how representative they are." Therefore, cases must be collected randomly and cover the problem domain as completely as possible.

Design/Implementation: This phase is concerned with the design of the representation of input attributes and output classes, and the implementation of the selected inductive learning technique.

Validation: This phase is to validate the performance of induced knowledge. A set of validation criteria and an induction-validation design (e.g., how to split cases between training and testing) need to be determined prior to the knowledge induction and validation. If the Backpropagation network learning technique is used, parameter-tuning experiments need to be conducted to determine the optimal network structure. Upon the completion of the above tasks, the knowledge induction and validation can be performed.

3 Problem Analysis and Inductive Learning Technique Selection

The problem domain of interest is to determine the relevance between prior examinations and the current examination, based on the the current examination information. Interviews, questionnaire survey, and protocol analysis techniques have been conducted in the University Medical Center at the University of Arizona in the problem analysis phase. Some important findings are summarized in the following, whereas the detailed results can be found in [5, 6, 7, 11].

13 input attributes which may affect the decision on prior image selection and retrieval were identified. As shown in Table 1, these attributes which can be classified into three categories: current examination-related, patient-related, and disease/abnormality-related.

The listing of prior examinations is not appropriate for the output classes because each current examination varies in prior examination number, sequence, time interval, reason, and etc. Three dimensions (anatomical portion, modality, and time/sequence) were identified to describe the patterns of prior examination selection/retrieval in a manner appropriate to construct the output

Category	Input Attribute
Current Examination Related	Anatomical portion of the examination Modality of the examination Reason of examination (e.g., post-injury tracing, etc.)
Patient Related	Sex of the patient General condition of the patient (e.g., satisfactory, etc.) Clinical status of the patient (e.g., urgent, etc.) Source of the patient (e.g., emergency room, etc.) Pregnancy type Use of alias (e.g., for trauma patient)
Disease/Abnormality Related	Type of disease/abnormality (e.g., mass, etc.) Cause of disease (i.e., congenital or acquired) Phase of disease (i.e., acute, subacute, or chronic) Type of mass if the disease type is a mass

Table 1: Input Attributes for Selecting/Retrieval Prior Images

Dimension of Prior Examination	Relationship with Current Examination
Anatomical Portion	• Same anatomical portion • Related anatomical portion
Modality	• Same modality • Related modality
Time/Sequence	• Recency † Most recent one prior examination † Most recent two prior examinations † Most recent three prior examinations • Specificity † Baseline examination with the same reason as the current examination † Most recent pre-operation examination • Interval † One week prior † Two weeks prior † One month prior † Three months prior † Six months prior † One year prior

Table 2: Dimensionality of Output Classes

classes. Table 2 provides a detailed description of these dimensions. Since the retrieval of multiple prior examinations was often observed, the output class space should include all feasible combinations of these three dimensions. A total of 26 output classes was constructed.

As indicated in the past studies [5, 6, 7, 11], the retrieval of prior examinations has the following characteristics.

Inconsistent retrievals: Different radiologists may demonstrate different retrievals for the same examination. The retrievals of prior examinations by the same radiologist for the reading of the same examination observed at different times may not be identical.

Incomplete input information: The input attribute values are extracted from consultation requisition form and/or examination form of the current examination. However, these information may not always be complete.

Multiple values for an input attribute: Not all input attributes are single-valued. For example, an examination may be for ruling out one disease as well as for tracing another disease. In this case, there are two values for the reason for examination attribute.

Multiple decision instances: During the interpretation of an examination with the existence of a tumor, for example, radiologists usually would retrieve a series of most recent prior examinations with the same modality and anatomical portion as those of the current examination.

These retrieval characteristics require the desired inductive learning technique be noise resistant, fault tolerant, and capable of handling both multiple values of input attributes and a decision with multiple instances. To meet these requirements, the Backpropagation network learning technique was chosen.

4 Design/Implementation and Cases Collection

The design of a Backpropagation network is concerned with representing the input attributes and the output classes in a set of numerically coded input nodes and output nodes. Two representation schemes have been proposed: 1) local representation in which every value of input attributes (or output classes) is assigned to an input (or output) node and 2) distributed representation in which a cluster of input (or output) nodes represents all possible values of an input attribute (or a dimension of output classes) [3, 8]. Unlike the distributed representation, the local representation is capable of representing multiple values for an input attribute and multiple decision instances. Thus, the local representation was adopted as the encoding scheme. As a result, a Backpropagation network for prior image selection/retrieval, containing 64 nodes in the

input layer, 26 nodes in the output layer, and a hidden layer whose number of nodes will be tuned during the validation phase, has been developed in C++ on DECstation 3100/25MIPS running Ultrix [4].

210 cases, targeting at both radiologists and residents in the University Medical Center at the University of Arizona, were selected from four radiological areas (chest X-ray, CT/MRI body, CT/MRI neuro, and musculo-skeletal X-ray) and were stratified randomly, based on reason for examination types. The stratified case collection reflects actual examination distribution with a reasonably complete coverage. The information (i.e., consultation requisition form and examination form) of each examination along with radiologists' retrieval of prior examinations were collected.

5 Validation

Two validation criteria were used for the validation of prior image retrieval knowledge induced by the Backpropagation network: recall rate (the percentage of the images used by radiologists that are actually suggested by the system) and precision rate (the percentage of the images suggested by the system that are actually used by radiologists). For tuning the parameters of the Backpropagation network, a set of experiments were conducted to determine the network topology (number of nodes in the hidden layer), the learning rate (how much of the weight change to have an effect on each pass) and the momentum factor (how much a previous weight change should influence the current weight). The experimental results suggested that 1) 100 hidden nodes, 2) dynamic (Search-and-Converge [1]) learning rate (with the initial learning rate of 0.25 and search time of 32), 3) and the momentum factor of 0 would offer the best performance. Thus, they were adopted in the validation task.

The cases were divided into two sets: training cases and testing cases. 10-fold cross validation technique¹[12] was used. Table 3 summarizes the validation results of the Backpropagation network learning and the KB acquired through the traditional knowledge acquisition approach [5] using the same set of cases. As indicated, both the recall and precision rates of the Backpropagation network learning are reasonably satisfactory when compared with those of its conventional counterpart.

¹Cases are assigned randomly into 10 groups. In each validation process, one group is chosen as the testing set and the rest as the training test. As such, the validation process is performed 10 times and their average serves as the estimate of the validation result.

	Recall	Precision
Backpropagation Network	78.84%	64.87%
Traditional Knowledge Acquisition	83.69%	73.05%

Table 3: Validation Results

6 Conclusion and Future Directions

The Backpropagation network learning technique with a well-defined research framework has been employed to induce prior image retrieval knowledge. The satisfactory validation result implies its applicability in the IRES development. Future related machine learning research for the IRES development includes 1) linking the developed Backpropagation network to operational PACS databases, 2) investigating explanation capability of the Backpropagation network learning technique, and 3) adopting symbolic learning algorithms (e.g., ID3) to facilitate the acquisition of image retrieval knowledge for IRES.

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SESSION 12

Teleradiology

Chair: Byrn Williamson

Teleradiology Extensions of the Mayo-IBM PAC System

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I. INTRODUCTION

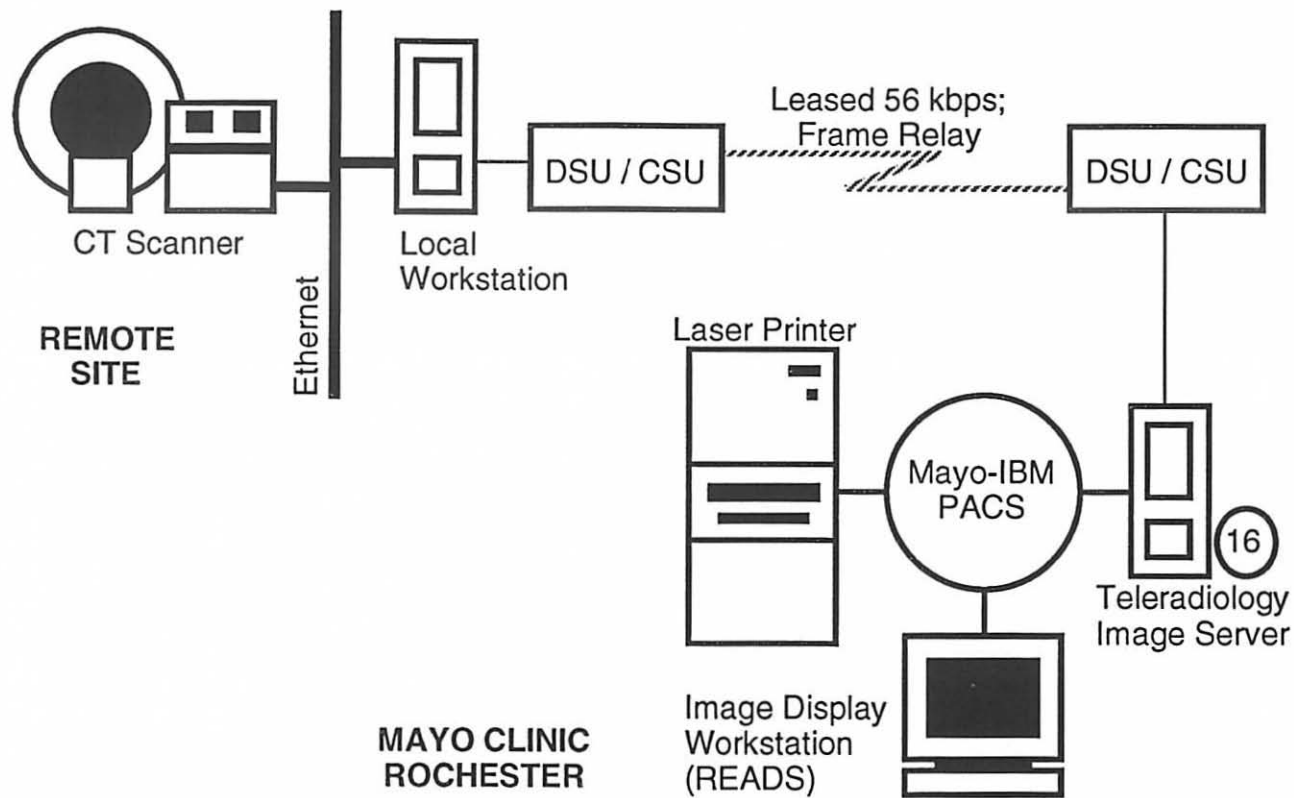
The Mayo-IBM picture archiving and communication system (PACS) [1] was designed initially to provide economical, automatic archiving of digital images from MR scanners on the Mayo Clinic campus in Rochester, Minnesota. This PACS also provides an excellent infrastructure for supporting teleradiology applications. The initial wide area network (WAN) extension of the PACS involved connecting PACS networks at the Mayo Clinic campuses in Rochester and Jacksonville, Florida, and Saint Lukes hospital in Jacksonville via T1 lines. This link occurred by virtue of the fact that the PACS components were placed on the Mayo institutional token ring network, and thus were able to communicate over the institutional T1 network bridges that were already in place. Digital images captured into the system at one location may be seamlessly retrieved to remote servers or modalities and viewed on remote workstations for consultative purposes.

More recently, a dedicated teleradiology system was put into place to provide primary interpretive services for CT studies acquired at a hospital affiliated with Mayo Clinic. This hospital is sited in Decorah, Iowa, 70 miles from Rochester. Initially, films were printed in Decorah and then manually transported by van (along with other clinical materials) to Rochester where an interpretation was rendered and then faxed back to Decorah. The time from CT study acquisition to report availability in Decorah was typically 24 hours or less. This system was acceptable for many scheduled examinations but was of limited use in emergency situations. A system based on electronic data transmission that could better handle emergent cases was designed and built. This dedicated teleradiology system will serve as the focus of this report..

II. METHODS

A block diagram of the initial electronic system is shown in Figure 1. This system operates in a very similar manner to the Mayo-IBM PACS. Upon completion of a CT study, native digital image data are automatically transferred using a DICOM-like protocol from the scanner to a local workstation over ethernet. The local workstation is an IBM PS/2 computer that performs much of the same function that an image acquisition unit (IAU) performs in the

Figure 1. Dedicated CT teleradiology system.



Mayo-IBM PACS. [1] Image data are converted to ACR-NEMA format and then compressed in a lossless manner using a commercial compression utility. The compressed data are then copied across the WAN using NFS. The WAN implemented for this project consists of a leased 56 kbps digital line running frame relay. After the CT study is completed, the indications for exam and other administrative data are faxed to Rochester.

A dedicated, 16-bit file server in Rochester receives the data, performs the decompression, and manages it in a serve directory for access by READS [2], one of the available PACS image review workstations. From READS, the study is viewed, formatted and printed to film on a laser printer accessible via the PACS network. The films and exam indications are then hand-carried to the radiology reading area appropriate to the type of study transmitted. An interpretation is rendered and faxed back to Decorah.

III. RESULTS AND CONCLUSIONS

This system was installed in October 1993, and since that time has been used to transmit 1-2 CT cases per day to Rochester. The total processing and transmission time is 85 seconds (s) per image, broken down as follows: 20 s for transfer from CT scanner to local workstation; 10 s for image reformat and compression; 50 s for WAN transmission; 5 s for decompression and READS management on the teleradiology file server. The time required to transmit and process a complete 50-image CT study is about 70 minutes. The time from CT study acquisition to report availability in Decorah is typically 2-3 hours for cases not marked as stat or urgent. Due to the locations of the available networked laser printers, system operation has been limited to use during standard Clinic working hours. The use of the current system has influenced patient management in several cases where the need to refer a patient from Decorah to Mayo was in question.

Improvements to the system are planned which will allow 24 hour, 7 day per week operation, on-line consultation, more rapid data processing and transmission and full integration into the existing Mayo-IBM PACS.

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Feasibility Study of Multi-Media Medical Image Consultation Over WANS

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1 Overview

The availability of high-speed networks, powerful display workstations and storage technology has spurred interest in developing a new *distributed* model for medical care based on the concept of a hospital linked to satellite clinics and physicians offices over high-speed networks. At SUNY, Stony Brook, the Multi-Media Image Consultation System (MICS) project jointly developed by the Departments of Radiology and Computer Science is aimed at developing groupware which would allow radiologists to consult and share image and patient data over a wide-area ATM network. A number of commercial entities have made wide-area networks available on Long Island: these include the NYNET Cooperative Research Network supported by NYNEX corporation, and FISHnet supported by Cablevision, Inc.

The MICS project supports a range of communication modes between participants, and will provide for the use of a range of multi-media technologies: video-conferencing, voice, use of shared pointers visible at both workstations, text and graphics. One form of supported consultation will allow simultaneous examination of patient folders by two or more medical personnel using pointing, voice and video-conferencing. An additional consultation mode will support communication between medical personnel in which the patient folder and other consultation details are packaged together as multimedia e-mail.

We intend to test the system by experimentation over proposed link between the Department of Radiology, University Hospital, Stony Brook and the Orthopedics Outpatient Facility in Setauket Technology Park. The Setauket Technology Park, located approximately three miles from the University Hospital, provides outpatient services (esp. follow-up visits) and generates X-rays which are currently physically transported to the Radiology Department for reading. Patients from the Outpatient facility may also be referred to the CT and MR imaging centers in the University Hospital. CT and MR studies are read in the Department of Radiology and reports are transferred to the Outpatient facility.

2 MICS Architecture

Figure I shows the hardware architecture of the system. Two display workstations are connected via the ATM network to an Image and Communication (I+C) Server. The I+C Server has 4 GB magnetic disk storage for short term archive of patient images. It acts both as an image server running a SQL database server and as a communication server running communication software that supports consultation. The ATM switch supports high-speed data transmission at current rates of 155Mb/s with plans to extend it to higher rates in the future (upto 2.5Gb/s).

With the widespread acceptance of the ATM model in large segments of the communication and computer-industry, it appears that such high capacity data links between clinics and hospitals may be available on a "fee-per-usage" basis in the near future.

Figure II shows the software architecture of the system as a sequence of layers. Each layer uses the functions provided by lower layers. UNIX (Operating System) and Motif/X-Windows (GUI) are standard software layers widely available on a range of hardware. The lower-level architecture makes use of a set of modules that provide software layers that hide details of communication. Standard medical imaging software is used to provide image-processing operations that may be needed in a consultation situation. Images are stored in a database using a SQL server and in a format that is closely related to the DICOM 3.0 standard accepted by the Radiology community.

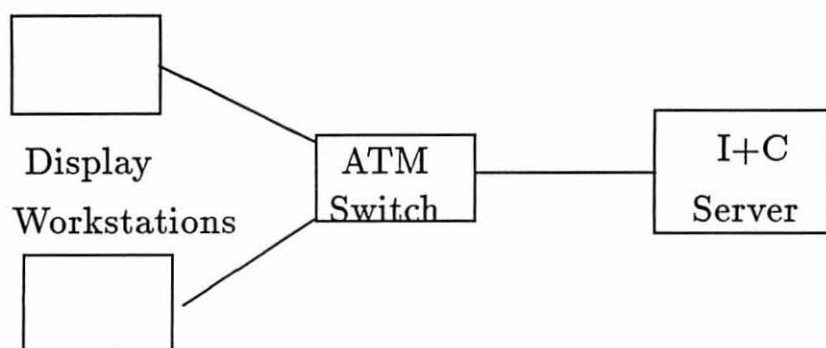


Figure I: Hardware Architecture

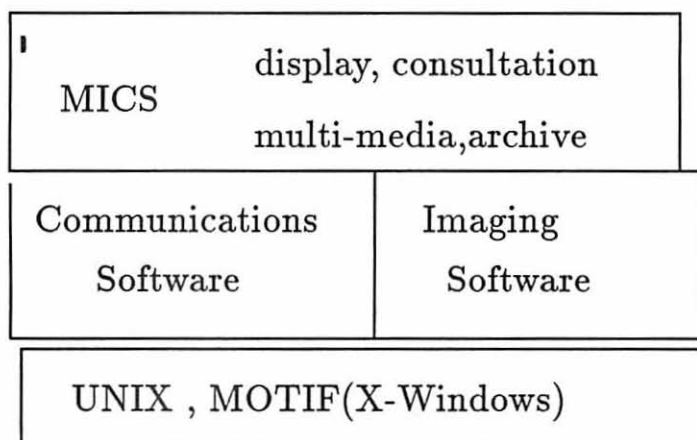


Figure II: Software Architecture

3 Research Issues

The enormous increase in connectivity offered by ATM network technology is both an opportunity and a challenge. There is little high-level software available for making use of the full-power of the ATM network. Industry-wide groups such as ATM forum are developing standards and APIs that will enable disparate groups of users to engage in Video and Audio Conferences, transmit large data files etc. We plan to carry out a range of experiments that will enable us to assess the adequacy of currently available software and hardware as used for medical image consultation.

We plan to develop a clearer characterization of a number of questions related to network capacity and hardware requirements such as: (i) size and character of network workload generated by Image Consultation, (ii) network configuration required to support such a workload, (iii) storage requirements for Image Storage, (iv) trade-offs between computing power, storage and network traffic in the system.

Finally, systems such as MICS must be accepted by many classes of users including both clinicians and administration. One aspect of the project is the development and investigation of a model for billing appropriate for consultation as well as investigation of the overall acceptance of the new model by clinicians.

4 Background

An excellent survey of the technology issues involved in this project may be found in [CMJB⁺92]. Detailed discussion of some of the issues in using digital displays may be found in [ACSK90]. A description of one of the earliest and largest experimental system for digital transmission of images may be found in [HRB⁺91]. Discussion of the use of multimedia tools within a hospital and between hospitals may be found in [TSA⁺92, OBANG92].

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Extending Teleradiology and Telepathology Services to Space Station

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1 INTRODUCTION

The future will see growing number of people working at Earth orbital, lunar and eventually Martian bases with long term exponential growth that will turn into permanent settlements. The efforts to inhabit planets will be complemented by extending medical care to personnel on these settlements. For practical reasons, only trained medical technicians with limited medical expertise can be available on sites to render preliminary health care. There is a need to extend radiology service to help in better diagnosis of illnesses. Technicians can operate image capturing equipment with the aid of expert systems. However, they need the expertise of a radiologist who is trained to recognize subtle details in diagnostic images. Thus, there is the need to communicate with medical experts on earth. Interplanetary image management and communication system (IIMACS) will deliver images acquired in space to radiologists at different medical centers on earth. This concept is telemedicine, can be used by radiologists or pathologists. It provides a facility to conduct conference sessions to diagnose these images. Furthermore, it helps to archive these images for research and teaching. The paper explores the state of space health care, and advances in space exploration. The paper discusses the implementation of IIMACS by extending Global PACS (GPACS) to different planets. Different user scenarios attempt to explain how IIMACS will operate. Our conclusion is that without incurring enormous cost, IIMACS is economically and technologically feasible by using the maturing technology base of GPACS.

2 SYSTEM DESCRIPTION

Image management and communication system (IMACS) will operate in a medical environment for managing digital images. Its components are: imaging equipment for acquiring the images, workstations for viewing the images, database archive system for storage and retrieval of images, and communication network for connecting all of these components in an integrated system. Recent research envisions a Global PACS (GPACS) that would utilize the National Education and Research Network (NREN) to cover a wide geographical area [1].

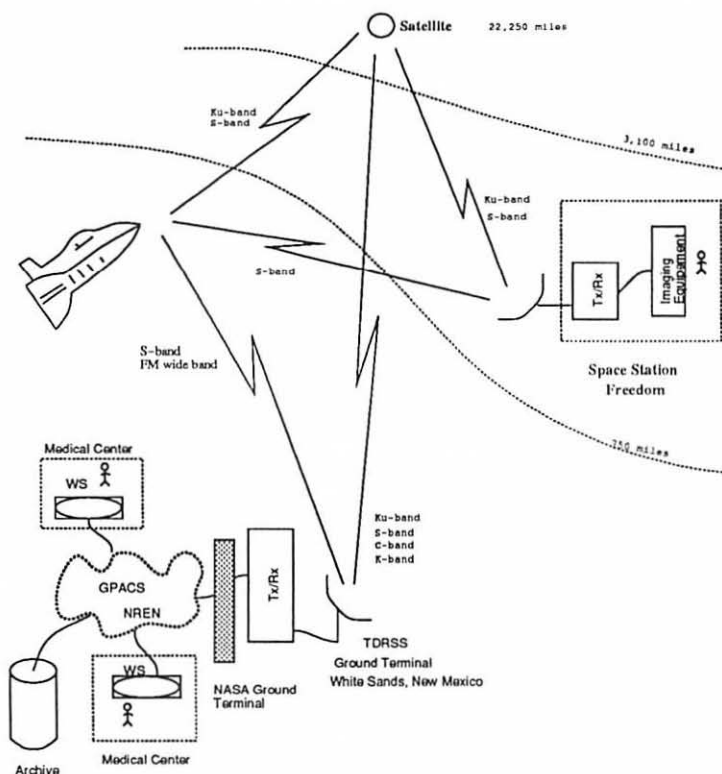


Fig. 1. Interplanetary IMACS System to Space Shuttle

Global PACS will provide teleradiology services to remote geographical locations. Moreover, it will allow timely diagnosis between geographically located experts. This facility will provide easy access to image archives for research and education.

2.1 COMPONENTS OF IIMACS

Interplanetary IMACS consists of three main components: space communication network, Global PACS system and the link between them at NASA Ground Terminals as shown in Figures 1, 2. These components are highly feasible using current technology. Two systems provide communication links between the Earth and the Universe. Tracking and Data Relay Satellite System is the main communication facility to spacecraft up to 3,100 miles. The deep Space Network offers communication with remote planets up to Neptune. The space communication network, using the Ku-band channels can accommodate the medical imaging data traffic. The Global PACS would utilize the NSFNET which is recently being upgraded to T3 (44.73 Mbps) lines.

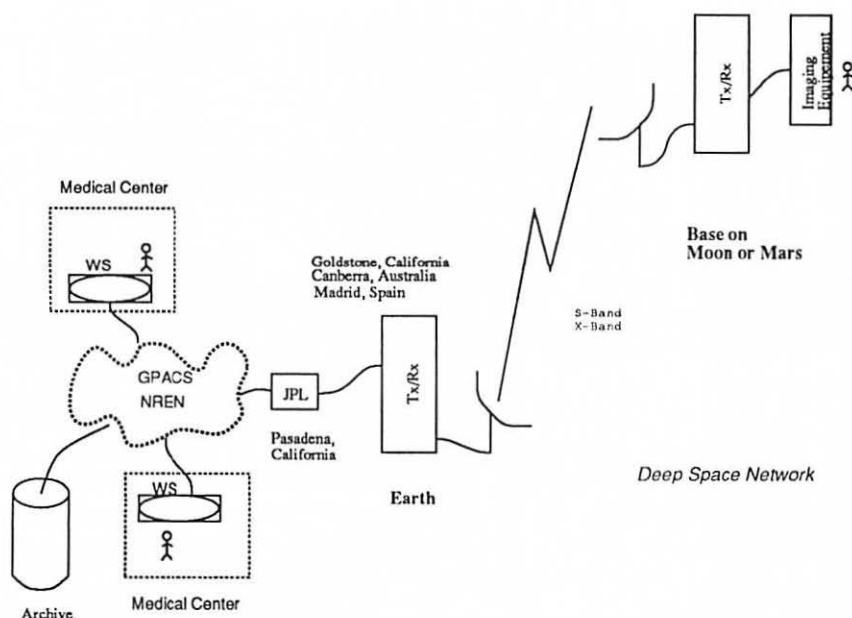


Fig. 2. Interplanetary IMACS System to Mars

2.2 EXAMPLE OF SPACE HEALTH CARE

Before human beings went to space, animals were sent as surrogates. Instruments monitored various physiological responses as the animals experienced the stresses of launch, reentry, and the weightless environment. However, we will not discuss issues related to the human body's response to microgravity or research and experiments attempting to test or confirm theoretical explanations of how the body reacts in space and why. We will try to focus on health maintenance facilities, designed to respond to trauma and illness, while astronauts are still in space.

Recent estimates indicate that a crew of seven astronauts, selected from the general population for a Mars expedition, would probably experience at least one medical problem normally requiring surgery [2]. This means trained personnel augmented by computerized health care systems and a link to medical experts on Earth are required for each expedition. Astronauts get initial training in the medical disciplines during the first year following selection. This medical curriculum encompasses approximately 16 hours of instruction during the year [3]. Crew members learn how to draw and process blood samples and record their own physiological symptoms [4].

On Space Station, the Crew Health Care System is located in the Habita-

tion Module [5]. It includes test and diagnostic instruments, a patient restraint, medical provisions to treat for illness and traumas that may be encountered during a mission, exercise equipment and an environmental health subsystem. The last mentioned includes instruments for microbiological [6], toxicological, radiation, and acoustics measurements. A computerized health care system keeps track of medical supplies, crew condition and checkup schedules. Astronauts will be able to monitor their health through vital signs, X-ray and blood samples using this facility.

2.3 USER SCENARIOS

This section introduces scenarios of IIMACS users. These scenarios are user location independent, i.e. no distinction is made whether the user is on Space Station, a lunar base or on Mars. These scenarios are based on existing practices in radiology. They assume the existence of space image acquisition devices that are similar to the radiology ones currently in use. We realize the need for new designs of these devices suitable for space deployment. These new designs will need to address implementation issues like power consumption, weight, size and image resolution.

At early stages of system deployment the personnel themselves or medical technicians will use the imaging equipment to capture images. Expert systems will help them in determining many variables before performing an imaging procedure and walk them through image acquisition protocol [7].

The images will be transmitted to earth via the satellite link. At White Sands NM, these images are transported over the NREN to a medical center where they are stored. An expert will examine these images, provide diagnosis and report the result back to the planetary station. The remote consultation and diagnosis scenario involves two or more medical experts each located at remote viewing workstations. They download the images and establish a consultation session for the purpose of examination. They both see the same image on their workstation screen. Each viewing workstation provides a pointer that allows the physician to point to sections of the image. When the physician moves the pointer, the remote site sees the resulting movement of the pointer on their images. Additionally, workstations have image processing capabilities that allow the doctors to analyze the image. These features are also displayed on the other consoles at the same time as the originating workstation. Voice interaction between the two doctors is possible. In order for all this to take place in real-time, only the pointing commands and image processing parameters are transmitted to the remote site.

In the interactive remote conference scenario, real-time imaging or video are transmitted to earth. The medical experts exchange digitized video, images,

voice and text in an interactive session. There may be more than two sites on the conference. This scenario enables experts to study images in real-time and provide feed-back to personnel in space.

This user scenario shows the collaboration between telepathology and telescience using IIMACS. Telescience is the combination of teleoperations and teleanalysis. Teleoperations concept enables a user to interact with a remote system as if that system was "next door". Teleanalysis extends the concept to ground processing of the system's data. It includes the ability to locate and extract useful data in distributed databases and archives, and to combine and reprocess these data to produce new datasets of increased utility. Telescience is a mode of investigation in which telecommunication resources are used for effective division of functions among ground facilities, and between ground and space [8]. These studies in remote control systems, will enable the extension of telepathology to planets. A technician on site can prepare the sample and set up the equipment. However, a pathologist on earth can conduct his study remotely, by studying images brought by IIMACS. Interplanetary IMACS will provide the forward link to carry commands to control the experiment

Medical research on humans and animals in space studies the effects of extended-length living in space environments with different gravity levels and high radiation doses. It studies the problem of bone demineralization, loss of body mass, nutrition, functioning of the body defense mechanisms, and dynamics of drugs administered in space to name a few. Using different imaging equipment to capture images of study items, and transferring them back to Earth by IIMACS. The National Library of Medicine, at Bethesda MD, is a natural candidate for the repository of these images. These images can be retrieved by researchers through the NREN network. Furthermore, when space is more inhabited by humans, these images will become an important teaching material in radiology departments. Medical researcher/radiologist in outer space can access these medical archives to view related cases.

3 CONCLUSION

Human ambition to establish manufacturing plants in space requires medical support. Global PACS is becoming a reality, providing a means of archiving and transferring medical images on Earth. Interplanetary IMACS is the natural extension for the growth of medical services with the growth of humanity. Current technology can support such a system, and the foundation for realizing it is being laid by providing to researchers access through NREN to images captured in space.

The establishment of this system will open the doors widely to medical services and research in outer space. Medical needs of humans in space as cases

of trauma and tumors can best be detected by radiology. Researchers need to address design features of image acquisition devices, such as size, weight and power consumption. Furthermore, we expect the extension of this system to non-medical applications of radiology such as testing mechanical parts and botany.

I like to acknowledge the fruitful discussion I had with Kevin McNeill.

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Rentability of Medical Desktop-Conferencing in Radiology

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Introduction

Modern concepts of telecommunication have the potential to radically change traditional habits in the medical world. Broadband-videoconferencing has already proven to be effective as a tool for further education and the integration of research programs at distant locations. However, it has not been able to position itself as a part of the clinical routine. Till now this has been mainly due to high costs of broadband-equipment and -networks necessary for satisfying speed and quality of image- and videotransmission. The introduction of ISDN¹ as a powerful narrowband network has brought up a perspective of inexpensive videoconferencing over public telephone lines. The actual concept has migrated to the use of a simple desktop-system offering an integration of medical imaging systems, hospital information systems and digital data bases. It has been created especially for the use in radiological departments.

Methods

The study has been designed to evaluate the rentability of Medical Desktop-Conferencing in radiology. To define the prospective need and effectiveness in relation to the costs the actual status of radiological service for two external locations in Berlin was examined. Those locations were a general practitioner and a 267-beds orthopaedic hospital with limited radiological facilities and no certified radiologist. Both locations were linked to the Department of Radiology of the Universitätsklinikum Rudolf Virchow in Berlin over ISDN during the ongoing study.

Over a 4-weeks-period all requested examinations, the data of demonstration of findings and the time until receivment of the final result were noted. Other focusses were the value of previous examinations and delay of therapy or prolonged hospital stay due to late arrival of radiological results. To estimate the costs of traditional demonstration of findings versus Medical Desktop-Conference an average wage of DM 150/hour (\$ 80²) per physician was considered. The average data relevant for the demonstration by Medical Desktop Conference was collected by analysing 20 MRI- and CT-examinations next to an additional 6 conventional images.

¹ Integrated Services Digital Network

² Exchange rate DM 1 = \$ 0.6

Finally, the on-campus Department of Oncology with a size of 20 beds and ambulatory treatment was taken for comparison. Criterias were identical to the above mentioned, the time period involved 2 weeks. The Department of Oncology has not yet been linked via network with the Department of Radiology.

Concept of Medical Desktop-Conferencing

Medical Desktop-Conferencing satisfies the needs of communication between two physicians, for example a radiologist and a referring physician. It does not meet the needs for communication with a large audience as traditional videoconferencing may do. A factor that has shown high regard is the importance of visual contact among communicating partners. Therefore a videotransmission with satisfying quality is integrated in the system. A "shared workspace" on screen for the radiologist and the consulting physician provides easy access to digital imaging systems as well as image- and data archives. Findings of the actual examination in relation to previous ones can be demonstrated and discussed over large distance directly after the images have been generated. It is optional to add a written report to the digital data- and image archive.



Medical Desktop-Conference

Systemconfiguration

The Medical Desktop-Conference system developed as part of BERMED³ is based on a standard Sun Sparc Workstation and being ported to HP and Alpha. Communication is provided via UDP and TCP/IP protocols. The network connecting external locations like the orthopedic hospital and the general practitioner is scalable ISDN, data transfer rate max. 2 MBit/s (Narrowband-ISDN S₂M, US: T₁-carrier 1,5 MBit/s). Participants need a router to distribute the data on 30 ISDN S₂M channels and synchronize at the receiver. Access to the system is regulated by passwords for identification.

The videotransmission uses JPEG compression and the Parallax Xvideo card. A concept of window-sharing creates a shared workspace for the users with selected windows replicated on the remote screen. Image processing tools (e.g. grey scale) are integrated. Access to digital imaging systems and data archives as well as to hospital information systems is managed by HDMS⁴. Analogue information such as

³ Under scientific direction of Prof. R. Felix, Prof. E.Fleck and Prof. B. Mahr and funded by DeTeBerkom research project BERKOM

⁴ Heterogenous Distributed Information Management System

ultrasound images or written documents may be scanned by a document camera. Demonstration of findings is supported by a real-time telepointer for each participant to show points of interest. An object oriented database management system, Itasca, is used as storage of patient information combined with image data. It has not been fully integrated in the clinical project yet. In the future there will be need for large scale databases to provide long-term on-line availability of previous patient data.

Costs of demonstrating radiological findings by Medical Desktop-Conferencing

The call set-up between the radiologist and the referring physician takes 30 seconds. To place 1 selected MRI- or CT-image on both screen takes 5 seconds. Conventional images such like a thorax take up to 15 seconds. The actual demonstration of an MRI- or CT examination demands 6 single images in average. For setup of those images 30 seconds have to be accounted. The average time to explain an image is 15 seconds, together 90 seconds. The dialogue at the end of the consultation takes 30 seconds. Adding this up leads to an average of 3 minutes per patient. Considering DM 150 per hour, the price for two physicians for 3 minutes is DM 15 (\$ 8). ISDN takes DM 6,90 (\$ 4,14) per unit (local area at daytime: 6 minutes). Altogether the demonstration of 1 MRI- or CT-examination costs DM 21,90 (\$ 13,14). The demonstration of conventional findings (2 images per patient) takes a total of 2 minutes. 30 seconds call set-up, 30 seconds placing the images on both screens, 15 seconds demonstration of each image, 30 seconds dialogue. Including wage costs of two physicians plus network charges this adds up to DM 16,90 (\$ 10,14) per patient.

As of March 1994 the workstation including the video-card and software estimates about DM 25.000 (\$ 15.000), the router for use of ISDN another DM 4.000 (\$ 2.400). The goal is to reach a package price of DM 15.000 (\$ 9.000) within a year's period via migration to a regular PC. The installation of ISDN S₂M ranges at DM 200 (\$ 120), the monthly rent is DM 518 (\$ 320,80).

Current service of the Department of Radiology at the Universitätsklinikum Rudolf Virchow

The Orthopaedic hospital orders just MRI- and CT-examinations. Conventional images are taken at own facilities. Since there is no radiologist at the hospital, the demonstration of radiological findings is held fortnightly by an Assistant Professor of the Department of Radiology of the University Hospital Rudolf Virchow at the external hospital. Besides that the patient gets a brief handwritten result by a radiological resident after the examination. The final result of a patient's MRI- or CT-examination is drawn up by a specialist and sent via mail.

Within 4 weeks, 28 MRI- and 20 CT-scans were ordered. In addition to the handwritten report the detailed final result arrived 10 days after MRI-examination, 15 days after CT. Previous examinations were of no interest in those cases. Demonstration of findings for 20 MRI- (71%) and 11 CT-patients (55%) took place in the fortnightly session. 4 conventional images taken at the Orthopaedic hospital were added for discussion. In a 4 week-period there were 8 MRI patients (28%) who had to wait for the radiologist's judgement before further treatment was possible. 5 of those patients had got a CT-scan as well (25% of CT-patients). Since in 4 of those 8 unclear cases

the time until the regular demonstration was unacceptably long, consultation by phone was necessary. The other 4 patients were delayed in treatment for an average of 3 days. The standard cost of 1 day in the Orthopaedic hospital is DM 450 (\$ 270), adding up to DM 5.400 (\$ 3240) for the above mentioned 4 patients.

The costs of immediate demonstrations through the Medical Desktop-Conference for the 13 examinations (8 MRI/5 CT) add up to $13 \times \text{DM } 21,90 = \text{DM } 284,70$ (\$ 170,82). Cost 4 patients' delay = DM 5.400 (\$ 3240). $\text{DM } 5.400 - \text{DM } 284,70 = \text{DM } 5115,30$ (\$ 3069,18) in savings. An advantage through the radiologist's early and possibly more precise diagnosis at an immediate demonstration of findings in all other patients can not be quantified. The costs of the traditional demonstration result particularly from the radiologist's wage costs. The travelling time per demonstration is 1 hour one-way. The demonstration takes an average of 50 minutes. Assuming that the wage of the radiologist is DM 150/h, the cost for 2 demonstrations in 4 weeks is DM 850 (\$ 510). The cost of demonstrating all 48 MRI- and CT-patients over Network and Medical Desktop-Conference would have been DM 1.051,20 (\$ 630,72). The earlier mentioned 4 additional conventional images presented at the traditional demonstration add up to another DM 67,60 ($4 \times 16,90$, \$ 40,56). The overall cost for Medical Desktop-Conference over 4 weeks would have been DM 1.118,80 (\$ 671,28).

The General Practitioner is serviced with brief handwritten reports after examinations in addition to the detailed result following by mail. There is no demonstration of findings. Within 4 weeks a total of 12 radiological examinations was ordered. Besides the handwritten report the full result of 2 CT-scans arrived after an average of 12 days, the result of 4 MRI-examinations after 9 days and the result of 6 conventional images after 3 days. Previous examinations were not consulted for those patients. The demonstration cost via Medical Desktop-Conference in 4 weeks would have been $6 \times \text{DM } 21,90$ plus $6 \times \text{DM } 16,90 = \text{DM } 232,80$ (\$ 139,88). Since all requests were out-patients, there were no savings due to reduction of hospital stay. The benefit of immediate treatment after detailed demonstration in good time can not be quantified.

A different premiss has to be considered for the comparison in the in-house Department of Oncology. There is a detailed daily demonstration of all radiological examinations that takes 35 minutes in average. Usually a handwritten report is not provided, the detailed result follows after demonstration by in-house mail. In a period of 2 weeks there was a request for 2 MRI-scans, 11 CT-scans, 3 Angiograms and 44 conventional examinations. At the daily demonstration, important previous examinations were missing in 2 CT-examinations (18%) leading to limited quality of the result and a prolonged hospital stay of 4 days in 1 patient. This prolonged hospital stay led to an increase of costs of $4 \times \text{DM } 730$ (\$ 438 = average charge/day, Department of Oncology) = DM 2920 (\$ 1752). Again disadvantages in therapeutic delay can be assumed.

Since there is a daily demonstration of findings by an Assistant Professor, the detailed report is not so important. MRI and CT 10 days, Angio 8, conventional images 1 day until receivment. Wage cost for the demonstration of findings is DM 875 (\$ 525) in 2 weeks for the Radiologist. In comparison, the demonstration by Medical Desktop-Conference and Campus Area Network would increase costs specifically through the extended time it takes to place conventional images. It has to be considered that Campus Area Networks have higher transfer rates than ISDN at 2 Mbit/s. Demonstration

time for MRI-/CT-findings is comparable to traditional demonstration since placing the images on screen takes as much time as to prepare for traditional demonstration.

Discussion

To create a Conference system that would show rentability in the daily use at a radiological department the development of inexpensive facilities was inevitable. Conventional videoconferencing does not only demand an expensive network infrastructure with fibre optics but usually goes along with lavish user hardware. Advantage is the opportunity of further education of large audiences through the use of large screens as well as full integration of research activities way apart. In contrary, Medical Desktop-Conferencing benefits of using a standard Workstation and ISDN over public phone lines. The concept has been designed to fit the needs of a "radiological service center" with easy demonstration of findings to external hospitals or general practitioners.

Looking at the actual service to the Orthopaedic hospital, the Medical Desktop-Conference will save costs by eliminating prolonged hospital stay. From now, the Orthopaedic surgeons can easily ask for the Radiologist's judgement in unclear cases. After the first month following the installation of the system this settles around 30% of cases.

An ambiguous aspect of the traditional demonstration every 2 weeks is that the patients discussed are only of interest for a minority of participating physicians. In the Orthopaedic hospital an average of 12 physicians is participating at those meetings each knowing only 10% of the patients demonstrated. This leads to 45 minutes unnecessary attendance per meeting, adding to 15 physicians $\times$ 2 meetings $\times$ 45 minutes = 1350 minutes. Wage cost for unnecessary attendance is $1350 \times \text{DM } 2,50 = \text{DM } 3.375$ (\$ 2.025) per 2 sessions. This amount cannot be added to the general cost of traditional demonstration though since there is the important effect of further education for the attending physicians. Consequently the traditional demonstration has so far not been canceled after installation of the Medical Desktop-Conferencing system.

The same argument fits the demonstration held for the Oncologists. Participating are an average of 10 physicians each knowing 30% of demonstrated patients. That leads to 20 minutes unnecessary attendance = DM 50 (\$ 30) per day and physician. In the evaluated time of 2 weeks this adds up to wage costs of DM 5.000 (\$ 3.000). Again, there is the factor of further education that will make the traditional demonstration inevitable. There is no win of time using the Medical Desktop-Conference for the in-house Oncology since findings are demonstrated daily anyway. The fixed date of the traditional demonstration helps to organize the Radiologist's day more efficiently without being interrupted at unexpected times for a Desktop-Conference.

A valuable addition to the system is a large digital image- and data base with on-line access to all patient data. Especially in patients with frequent examinations conventional image archives tend to be incomplete with a great loss of important information especially in oncological therapy. Ideally there is an access to the data base on the ward as well as at the demonstration via Campus Area Network.

As a result of the factors focussed in the study, no instant measurable reduction of costs by offering the Medical Desktop-Conference to the General Practitioner was

shown. An important point we have not accounted for are savings through avoidance of double-examinations when patients are referred to a hospital or a different physician. The Medical Desktop-Conference combined with the digital data base allows the complete transfer of patient data and images to any location. The same procedure will provide a complete report sent to the physician in practice including results and images of examinations to optimize the patient's treatment after leaving the hospital.

The data transfer rate of ISDN S₂M at 2 MBit/s provides placement of MRI- and CT-images on participating terminals in short time without any loss of information. However, the time of transfer for conventional image has to be improved. A useful completion of the Medical Desktop-Conference would be the option for the immediate preparation of a written report during or after the demonstration. To save the radiologist's time the text processing should work with prepared text elements ideally combined with a speech processing device as presented lately by major computer companies. Quality control of the Radiologist's job through Medical Desktop-Conference may lead to improvement in the relation to external physicians. The better service will strengthen the ties to physicians in practice or external hospitals. After installation of the system the General Practitioner has demanded a demonstration of findings of all transferred patients. On the other hand there may result problems in the Radiologist's compliance as a reaction to "tight control". Rising demands in quality control will be a strong argument against this kind of reluctance.

In summary the in-house Department of Oncology obtains no major advantage by the use of the Medical Desktop-Conference except for the easy access to previous examinations. Nevertheless the Medical Desktop-Conference has proved to increase diagnostic and therapeutic quality and a great potential in cost savings when serving external hospitals or physicians in practice. The acceptance of the Medical Desktop-Conference via ISDN by the staff of the Orthopaedic hospital and the General Practitioner has been highly encouraging.

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Network System for Medical and Radiological Check-up

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I. INTRODUCTION

At present the radioactive background in most of the regions of Ukraine considerably exceeds the natural one. Only due to Chernobyl disaster about 450 types of radioactive isotopes were blown out in atmosphere. There was a number of long-living isotopes among them. The contamination of soil and air exceeds the permissible level not only in made sanitary zones but far away due to "speckled" character of fall outs on the ground. Radioactive substances penetrate into a human body with food and air and accumulate there. Even low radioisotope concentrations accumulated in organism are danger to health of people having permanent residence in polluted area. The radioisotopes accumulation can also results in fatal consequences for descendants' health. That is why the problem of the large scale medico-radiological monitoring of people living in contaminated regions is of vital importance. To carry out the check-up in wide territories, it is necessary to create a network of similar high sensitive devices that can measure γ -radioactive isotope count of human body, food, water and other samples, accumulate this information and record it into a data base. The devices conjugation into a network allows to systematize the information received from each device.

We have created such a device (module of medical and radiological control-MRC module.). It enables to control efficiently the radioactive contamination of people and samples and provides centralized processing, storing and expedient use of the collected information including the results of medical check-up. A number of the devices has yet united into a network.

II. EQUIPMENT

Network MRC is a system of automated measuring modules connected with the main coordination and information center by means of modems through telephone communication. Each module MRC comprises: 1. Human whole body γ -spectrometer. It is designed as a diagnostic chair with built-in detector, protection system and electronic equipment. It is highly sensitive. (Minimal detected activity (MDA) for Cs137 is 2 - 5 nCi for 3 min. of measurement); 2. γ -spectrometer for food, water and other samples (MDA is 0.5 Bq for Cs137 for 10 min. of measurement); 3. PC/AT; 4.. input/output channels for automatic diagnostic medical equipment (such as cardiograph, blood analyzer etc.). The use of original software makes possible to determine extra low radioisotopes concentration in human body and samples, to achieve highly reliable measuring results, to automate the course of measuring and the data processing. The measuring method is based on the γ -spectrometry in the wide spectral range (0.1-2.0 Mev).

III. RESULTS

Before the beginning of γ -activity measurement it is necessary to fill in a questionnaire that is displayed. Received information is written in a data base. It is also possible to introduce in it the results of patients' medical check-up. There are a number of stage of received γ -spectrum processing: the background radiation subtraction taking into account human anthropometric parameters; statistically resolved peaks search and their center of gravity location; the determination of peaks amplitudes, energy and squares; radioisotope identification using a specialized expert program. All these stages are displayed. One of the γ -spectrum processing stages is shown in the Fig. 1.

The next stages of γ -spectrum processing are: real whole body γ -activity calculation and its value reduction to average weight (70 kg); dose evaluation. Diagram of whole body γ -activity for a number of isotopes received from spectrum processing is shown in Fig.2.. After the course of measurement and processing is finished, the certificate contained the activity and dose values is printed out automatically and all information is recorded in

Isotope Cs 137: center-353; ampl.-78, energy 662 kev; S-2516
 Isotope; center-590; ampl.- 1, energy 1101 kev; S- 66
 Isotope K 40; center-799; ampl.- 6; energy 1461 kev; S-247

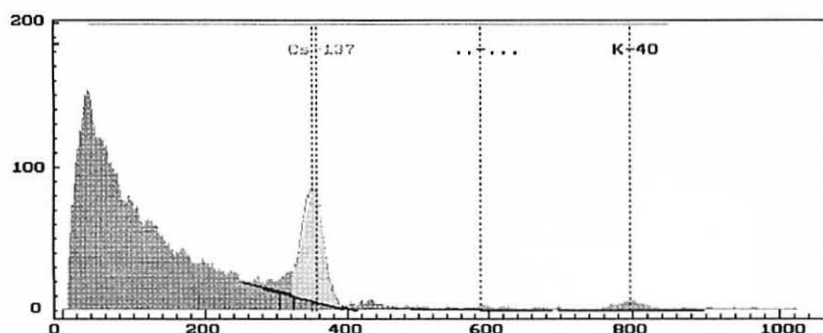


Fig.1.

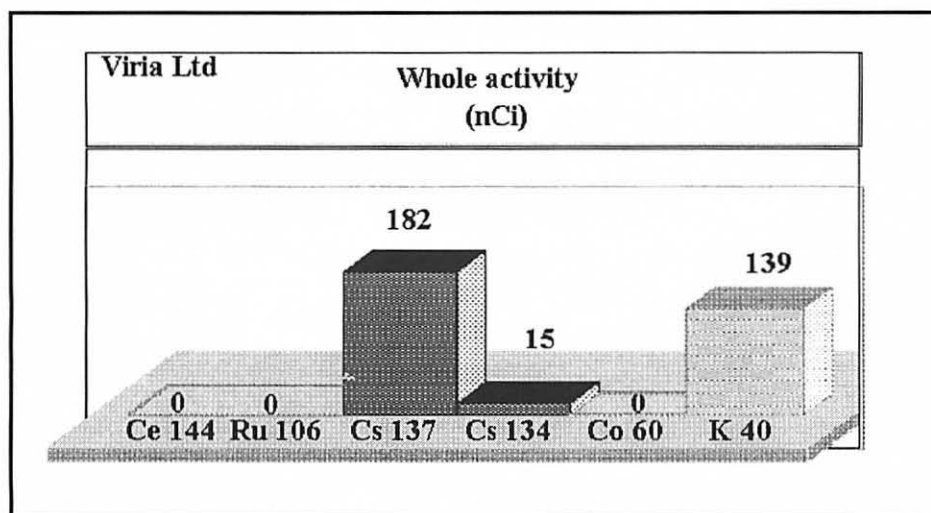


Fig.2.

data base. A consumer of MRC module can also receive the results of the peoples' γ -activity depending on the anthropometric, territorial, professional and other parameters. For example, the results of the statistical processing of data base received in the course of half-year from module MRC that was established in the district hospital of town Zarechnoje are presented in this paper (fig. 3-4).

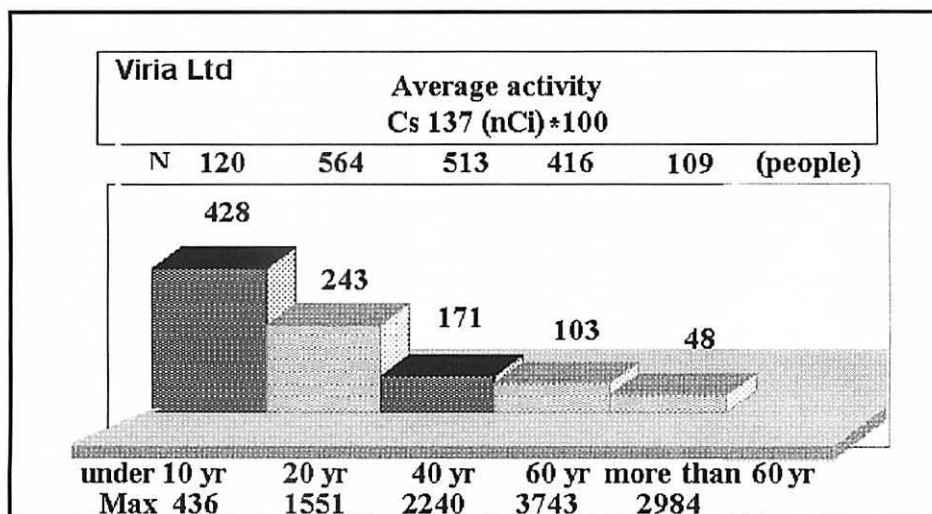


Fig.3

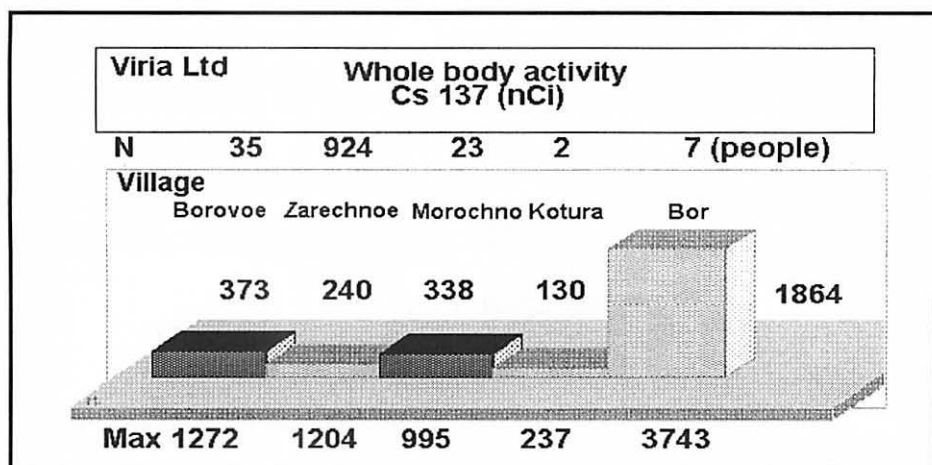


Fig.4.

The data bases was obtained for 2000 people living in the neighboring village. The statistical analysis shows that children under 10 years are exposed to danger to a considerable extent (Fig.3). The exponential abatement of radioisotopes accumulation with the human age growth is observed. The whole body γ -activity of people depending on the place of residence are presented in Fig.4.

IV. CONCLUSION

Using Network MRC it is possible to carry out mass regular radiological and medical check-up, to accumulate and to systematize the information received from each separate module in order to detect the most dangerous areas for living, to select "risk group" of people and to plan a number of steps to provide the safety of population.

Diagnostic Imaging Through High Speed Network: A Radiological Experiment on the Florence and Pisa MAN

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INTRODUCTION

It is now recognized that teleradiology plays a key role in providing means of displaying and generating consultations, in allowing the remote processing of images, in supporting research and educational activities. However, the most successful teleradiology applications have been those directly aimed at improving patient care. In Radiology, better patient care means higher quality of the diagnosis, and its timely availability. Teleradiology can impact on diagnostic quality both allowing the production of better diagnoses (remote expert consultation, remote access to databases of reference images) and helping to reduce some of the bottlenecks that prevent timely access to relevant information (previous exams, clinical data, etc). Moreover teleradiology can improve the communication between the radiologist and the referring physician by making the diagnostic images more efficiently available as well as by allowing the physician in charge of the therapeutical decisions to seek further support from the radiologist (in terms of a more focused description of images, or of a discussion on diagnostic alternatives, etc).

Teleradiology has also been proposed for didactic purposes since it allows the students to interact with experienced teachers, no matter where located, with minimal logistical disadvantages. Also research can benefit from teleradiology, that provides for the collection of homogeneous series of cases, even if acquired in different locations. Finally teleradiology can solve problems in terms of more efficient resource sharing and deployment (particularly relating to advanced image processing). All these aspects can benefit from fast communications links that enable to overcome the limitations imposed by the physical distance between general radiologist and expert, between radiologist and clinician, between the place where the images are produced and the place where they are processed (1, 2, 3).

In this study we describe the system that allows an intercenter management of radiological images using the intrconnected broadband Metropolitan Area Networks (MAN) presently operating in the two Italian towns of Florence and Pisa.

GENERAL OVERVIEW OF THE MAN PILOT

In the framework of the Telecommunication Project, a 5-year Italian research project promoted and funded by the National Research Council (CNR), several pilots have been implemented to explore the use of new telecommunication services in a broadband environment. Application domains include telemedicine, environmental telemonitoring, teleteaching and remote assistance for disabled people. A pilot in the Tuscany region, providing MAN facilities in the towns of Florence and Pisa has been realized with the aim to interconnect nodes located in University Hospitals, in other University Departments and in CNR Institutes. Experimentations regard various applications involving transfer, processing and storing of data, voice and still or moving images (4, 5).

The major objectives of this field trial, that started in 1992 and is going to be completed in mid 1995, are the following:

- selection of user requirements for applications needing high speed networking;
- identification of applications with the perspective of a wider diffusion in the future broadband scenario;
- definition of functional procedures to develop high speed applications;
- performance evaluation of MAN technology;
- evaluation of the impact on the user environment of advanced communication services.

The field trial layout is shown in Fig. 1, where the topology of the Tuscany MAN is depicted, encompassing 27 access nodes in the subnetworks of Florence and Pisa. The MAN follows the guidelines of IEEE 802.6 standard (DQDB, Distributed Queue Dual Bus). It is worth noting that the infrastructure used in the pilot is provided by two vendors developing network equipment implemented with the same QPSX technology, while the scenario is of course wider for the user access equipments.

In both cities a backbone operating at 140 Mbit/s interconnects the Edge Gateways (EGW), the Customer Network Interface Unit (CNIU) and the SMDS Access Unit (ACS). Each EGW has a 34 Mbit/s customer access network interconnecting a Customer Gateway (CGW). The CNIUs are interfaced with routers allowing, on the user side, access for LAN (Local Area Network), while the ACS provide a 2 Mbit/s SMDS (Switched Multimegabit Data Service) access. The subnetworks in Pisa and Florence are interconnected, via Subnetwork Routers (SRs), by a link which is about 65 km long and operates at 34 Mbit/s.

The user access to the network, through the CGW, is made possible either by 10 Mbit/s Ethernet LAN interface, with bridge functionalities, or by 2 Mbit/s isochronous interface, based on Rec. CCITT G.703. Moreover, to allow the access for a wider set of users with data communication needs that can be satisfied by medium bit rate links (2 Mbit/s), some CNIUs have been provided. In order to test on field the interoperability of SMDS with the LAN interconnection service provided on the MAN, a couple of users for both subnetworks has been equipped with direct 2 Mbit/s SMDS access.

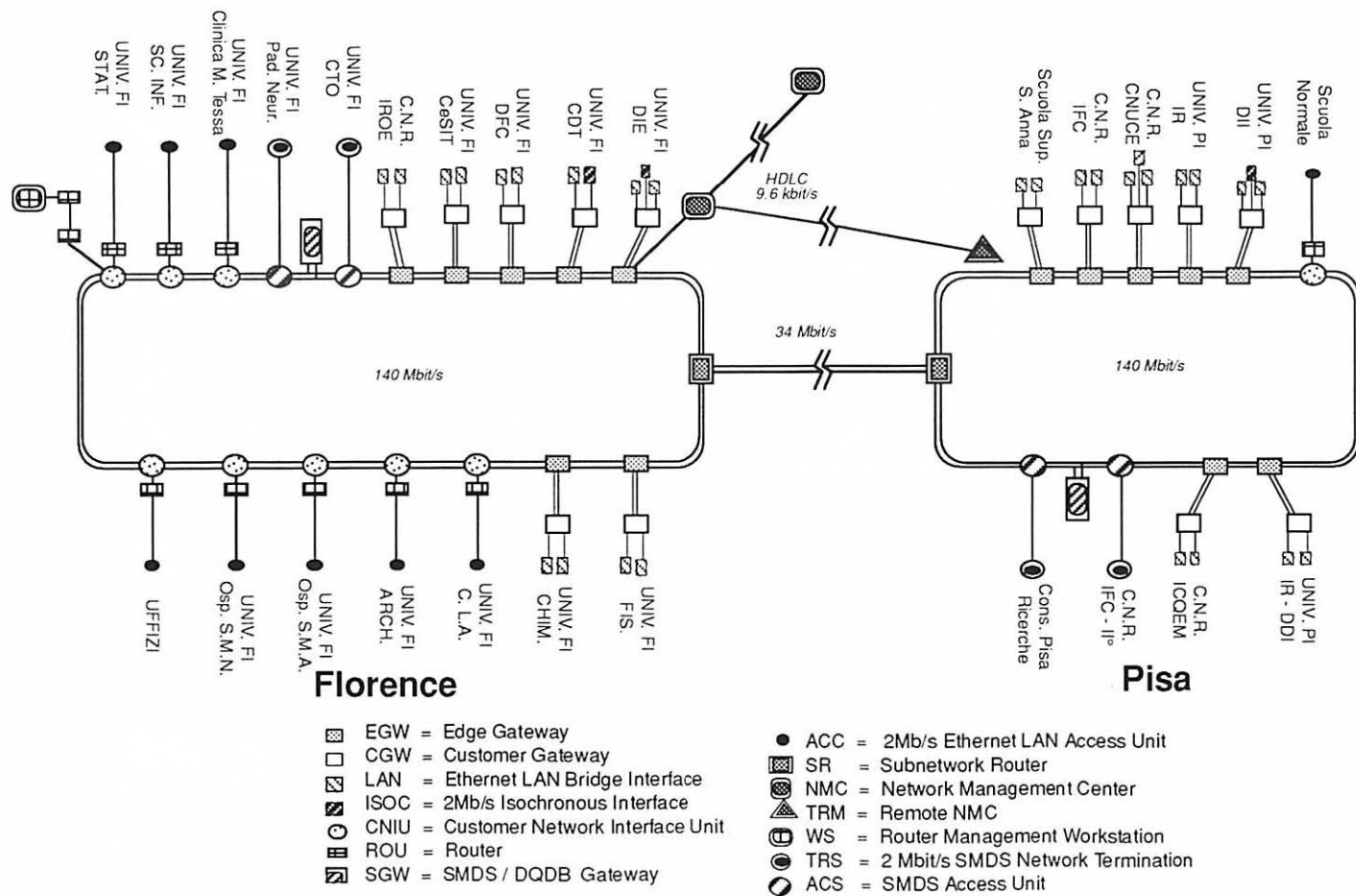


Fig. 1: General layout of the Tuscany MAN

CURRENT EXPERIENCE

In the Departments of Radiology of the Universities of Florence and Pisa a coordinated PACS development has been carried out since 1990, as a joint research program between the two radiological teams and some industrial partners (6). The present implementation consists of 6 Silicon Graphics workstations connected to MR, CT, DSA and US, in Florence, and 2 Silicon Graphic workstations connected to MR, CT, US, and a laser printer, in Pisa. Mass storage is ensured by 56 and 20 GByte juke boxes, respectively. In both sites the PACS networks are compliant with the IEEE 802.3 (Ethernet) standard and are connected to the MAN since February 1993.

Such high-speed network link as well as the homogeneous software environment proved suitable for integrating distributed imaging centers: namely, the MAN connection is being used by the radiologists in Florence and in Pisa with three main objectives:

- remote expert consultation
- didactic applications
- teleprocessing

Remote expert consultation

Remote expert consultation enables the access to the professional knowledge and expertise of distantly located radiologists, when the interpretation of some specific case might be particularly demanding (7).

An example of remote consultation between Florence and Pisa concerns the nonsurgical treatment of Hepatocellular Carcinoma (HCC). As it is well known, HCC is one of the most common malignancies in the world. However the patients with HCC that are eligible for surgery is very low, mainly due to the severity of the associated liver cirrhosis. Therefore, the therapeutic management of unresectable HCC has become a relevant issue, and several nonsurgical treatments were proposed. Percutaneous ethanol injection performed under sonographic guidance was proved able to achieve a complete necrosis of small (3 cm or less) HCC tumors (8). In larger tumors, transcatheter arterial chemoembolization using an oily contrast medium mixed with an anticancer drug followed by the injection of gelatin sponge particles is widely used. Recently, the possibility to profitably associate arterial chemoembolization with ethanol injection therapy was demonstrated (9). However, the selection of patients that may be eligible for one of the three aforementioned nonsurgical treatments often requires the consultation of an expert interventional radiologist. The MAN allowed radiologists from Florence (where nonsurgical treatments of HCC are not performed) to efficiently consult their colleagues in Pisa to ascertain whether a patient carrier of HCC lesions might have been sent to Pisa for nonsurgical treatment. The consultation required that the radiologists at both sides evaluated and jointly commented a large amount of image data: for doing that efficiently the broadband link proved indeed necessary (3).

Didactic applications

Remote case presentation and discussion, telelecturing, consultation of a distant image database are able to enhance continuing education for radiologists and to improve their diagnostic performance. These applications differ from the remote expert consultation because the purpose is not to solve actual clinical cases, but rather to illustrate a pathological condition and its typical features when examined with various imaging modalities.

The MAN allows a high-performance distributed access to the Florence image reference data base (IRDB). Such data base was first developed in the period from January 1989 to December 1991 as part of the contribution of the Department of Radiology of the University of Florence to Telemed, a European project in the framework of the RACE (Research & Development of Advanced Communications in Europe) Programme. The Telemed IRDB, enables the radiologist to retrieve "reference" images of normal and abnormal conditions (6).

Teleprocessing

Remote processing of diagnostic images is a teleradiology service that empowers the radiologist with the resources needed for advanced image processing without the necessity to purchase hardware and to acquire specific know-how. In fact the images to be processed are sent to scientific institutions where the processing is actually performed and from where the outcome is sent back for clinical evaluation.

Teleprocessing trials carried out over the DQDB MAN proved able to better the cooperation between the clinicians and the scientists who participated to the teleprocessing trials. Remote processing using high-speed communications enhanced the clinical applications of advanced image processing, which was previously impaired by the complexity of image transfer and the difficult and untimely feed-back of the radiologist to the engineer, concerning the clinical usefulness of processed images.

DISCUSSION

In our experience, the availability of digital communication services able to meet the requirements for a high-resolution high-throughput teleradiology allowed us to test a wide range of teleradiology applications. In fact, although we never used the MAN for primary diagnosis, since both radiological centers were "self-sufficient" to that purpose, we experienced the usefulness of remote expert consultation, that was previously performed with much less frequency, despite the frequent intra-institutional exchanges. Moreover, interactive teleprocessing of radiological images allowed an immediate feed-back of the radiologist, concerning the clinical value of the image processing technique adopted. Finally, the possibility to share the teaching archives of the Departments of Radiology of the Universities of Florence and Pisa did enhance the learning opportunities of the residents and radiologists working at both institutions.

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SESSION 13

Workstations

Chair: David E. Avrin

A Comparison of Film and Screen Interpretations of Radiographic Examinations Performed in the Emergency Department

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INTRODUCTION

Improving computer technology and availability of high speed telecommunications has increased the feasibility of teleradiology as a means of delivering radiological services. This is especially desirable in the emergency department setting, where immediate accurate interpretations of radiographic examinations are often crucial to patients' diagnosis and treatment. If teleradiology is to be used as the primary reading mode, interpretations made with the digitized films displayed on a teleradiology workstation must be as accurate as those made with conventional radiographic films. Several recent studies (1,2) have concluded that workstations are capable of supporting diagnostic performance equal to film. Previous studies (3,4) conducted in our radiology department, however, have shown that workstations do not support acceptable performance for primary diagnosis of typical emergency department radiographic examinations.

The objective of the present study is to compare the accuracy of interpretations based on conventional film readings with that from digitized images displayed on a teleradiology workstation. In addition to sensitivity and specificity, a Receiver Operating Characteristic (ROC) analysis is used to detect any significant differences between the two reading modes. The cases selected for the study were skewed toward the difficult so that the capabilities of the film and teleradiology systems would be tested stringently. Readers from both the emergency and radiology departments participated in the study to determine acceptability of the teleradiology system.

METHODS

Radiographic Case Selection:

Original film cases were selected from clinical practice at The Johns Hopkins Hospital by a senior radiologist (W.W.S.), who confirmed the selection with a senior emergency physician (W.M.). Neither was a reader in the study. Thirty-eight chest exams, twenty abdomen exams, and sixty-two bone exams were chosen, with the

selected abnormalities listed in Table 1. The "gold standard" interpretation for each of the 120 cases was determined by two of the authors (W.W.S. and D.A.B.). Half of the cases for each type of exam were identified as positive for one of the selected abnormalities. The same two authors also assigned a relative diagnostic difficulty rating of low, moderate, or high to each case.

TABLE 1

Selected Abnormalities

Chest:

pneumothorax (6)
cavity lesion (1)
mass (7)
infiltrate (5)

Abdomen:

pneumoperitoneum (4)
air in portal vein (1)
pneumatosis (2)
small bowel obstruction (3)

Bone:

assorted fractures (total 32) such as:

sacrum	mandible
olecranon	femur
metacarpal	scaphoid
pubic ramus	scapula
C1	radius
C2	

After all readings were complete, a consensus panel of two radiologists and two emergency medicine physicians verified the "gold standard" interpretation for each case that was missed by three or more of the eight radiology readers, or three or more of the eight emergency readers. The original interpretation was changed in only one case.

The consensus panel also reviewed each of the 120 cases and identified 31 as "critical" (Table 2). In these cases, an immediate, accurate interpretation of the exam was considered critical to the patient's emergency triage and care.

TABLE 2

Critical Cases (n=31)

pneumoperitoneum (4)	pneumothorax (6)
small bowel obstruction (3)	pneumatosis of bowel (2)
fracture tibial plateau (1)	air in portal vein (1)
fracture frontal bone (1)	fracture C1 (1)
intertrochanteric femur fracture (1)	fracture C2 (5)
false-positive pneumothorax (6)	

Readers:

Sixteen readers participated in the study: four emergency medicine faculty, four second-year emergency residents, four radiology faculty, and four second-year radiology residents. Each reader was trained in the use of the display workstation and the form designed to record study information. In four sessions of 30 cases each, the sixteen readers interpreted 60 cases on the original films and 60 cases on the teleradiology workstation. The order of case presentation for each session was randomized.

Minimal clinical histories were provided for each case, e.g. "motor vehicle accident" for bone cases, "cough and fever" for chest cases, and "abdominal pain" for abdomen cases. For each interpretation, readers recorded confidence and relative difficulty ratings of low, medium, or high, and gave their opinion of the technical quality of the images.

Teleradiology System:

The original radiographs were digitized using a laser digitizer with a spot size of 105 microns and a maximum resolution of 4096 by 4096 pixels. The digital data were then compressed to 2048 by 2048 pixels and transmitted over a T1 line (1.5 Mbits/sec) to an optical jukebox for permanent storage.

For each reading session, the specified cases were transferred to local storage at the workstation for display on two Vortech PDS monitors with spatial resolution of 1200 by 1600 pixels. The workstation was located in a screened area in the pediatric radiology reading room. Each digitized image required five to nine seconds to be displayed from local storage. Once an image was displayed, functions such as contrast/brightness (window/level) control and magnification were available to the reader. When images were displayed at original film size, 1.6 line pairs/mm could be resolved. With full magnification, this improved to 2.0 line pairs/mm.

Analysis:

Diagnostic accuracy, sensitivity, specificity, and ROC values were calculated to measure the results of the study. Accuracy is the percentage of correctly diagnosed cases (true-positives plus true-negatives divided by the total number of cases). Sensitivity is the percentage of correctly diagnosed *positive* cases (true-positives divided by the total number of positive cases). Specificity is the percentage of correctly diagnosed *negative* cases (true-negatives divided by the total number of negative cases). The McNemar test was used to compare differences between film and screen values by calculating the one-tailed probabilities (p-values).

The ROC analysis began with the pairing of readers within the four groups such that each *pair* had read every case on both film and screen. Readers from the same department and of the same status were paired so that similar confidence thresholds and diagnostic experience were combined. Thus, eight correlated data sets were produced for analysis using the computer program CORROC2 (Metz, CE, U. of Chicago, 1989), resulting in eight sets of ROC indexes.

RESULTS

The overall performance of all readers for all cases by mode is shown in table 3. The accuracy and sensitivity for film readings are significantly higher than those for screen readings.

TABLE 3

Reader Performance by Mode
(960 readings in each mode)

Measure	Mode (percentages)		Probability
	Film	Screen	
Accuracy	64.5	57.3	$p < .025 *$
Sensitivity	50.2	39.6	$p < .025 *$
Specificity	79.2	75.6	$p > .1$

* statistically significant difference

Tables 4a and 4b include data from emergency department readers only. Table 4a shows results by mode for all cases while table 4b is limited to critical cases only.

TABLE 4a

All Cases - Emergency

Measure	Mode (percentages)	
	Film	Screen
Accuracy	54.8	49.2
Sensitivity	38.1	29.1
Specificity	72.0	69.9

TABLE 4b

Critical Cases - Emergency

Measure	Mode (percentages)	
	Film	Screen
Accuracy	48.4	36.6
Sensitivity	44.0	34.0
Specificity	66.7	45.8

Tables 5a and 5b include data from radiology department readers only. Table 5a shows results by mode for all cases while table 5b is limited to critical cases only.

TABLE 5a

All Cases - Radiology

Measure	Mode (percentages)	
	Film	Screen
Accuracy	74.2	65.4 *
Sensitivity	62.3	50.0 *
Specificity	86.4	81.4

* statistically significant difference

TABLE 5b

Critical Cases - Radiology

Measure	Mode (percentages)	
	Film	Screen
Accuracy	82.3	67.7 *
Sensitivity	81.0	68.0 *
Specificity	87.5	66.7

* statistically significant difference

For all 120 cases and the 31 critical cases, radiologists' and emergency physicians' interpretations demonstrated more accurate diagnoses on film than screen. Also, interpretations by radiology readers on screen resulted in higher performance values than interpretations by emergency readers on film. This is true for both "all cases" and "critical cases" which suggests that in a teleradiology setting where emergency physicians have access to original films and can obtain electronic consultation with radiologists at workstations, patient care will benefit.

Table 6 shows all readers' performance by diagnostic difficulty by mode. The accuracy, sensitivity, and specificity for film and screen interpretations are almost equal for low difficulty cases. For the moderate and high difficulty cases, film performance is superior to screen performance.

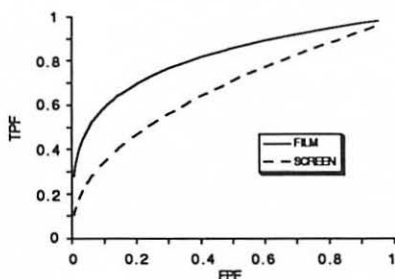
TABLE 6
Reader Performance by Difficulty and Mode

Measure	Diagnostic Difficulty					
	Low		Moderate		High	
	Film	Screen	Film	Screen	Film	Screen
Accuracy	83.8	82.8	61.7	49.4 *	46.1	38.2
Sensitivity	66.1	66.1	54.7	40.5 *	40.5	31.0
Specificity	87.5	86.4	74.2	65.6	60.0	56.3

* statistically significantly difference

The ROC results for all radiology readers are shown in figure 1. Because of differences in confidence and reading experience, the emergency department results could not be combined with the radiology department data. The areas under the film and screen curves are significantly different (one-tailed $p=0.01425$). This clearly indicates the superior performance of the readers when basing interpretations on conventional film examinations compared to their use of the teleradiology system.

FIGURE 1
ROC results for all radiology readers
($p=0.01425$).



Questionnaire Results:

After the reading sessions were completed, each reader responded to a questionnaire concerning aspects of the study design, the reading environment, and the functionality of the teleradiology workstation that may have affected their interpretations.

Most readers were satisfied with the spatial resolution of the teleradiology system; however, it was necessary to magnify many of the images to achieve visualization of potential abnormalities. The image display time from local storage (>5 sec) was considered by many readers to be too slow. Readers also noted that the image manipulation functions were cumbersome and time consuming.

The reading environment was also criticized; several readers wanted a more private reading area with fewer distractions and better lighting. A few readers stated that longer, more intensive training sessions on the teleradiology workstation could have improved their performance. Half of the radiologists and all of the emergency readers stated that more clinical information regarding the indications for the examination might have improved their performance.

DISCUSSION

The results lead to the conclusion that the teleradiology workstation evaluated in this study is not acceptable for primary interpretation of emergency department radiographic examinations. However, the technological advances needed to resolve the deficiencies seen in the teleradiology system are under way, and will soon be available to develop a system that is acceptable for primary clinical diagnosis.

Emergency department physicians are primarily concerned with the accuracy of interpretations of radiographic examinations that are critical to patients' emergency care. For these cases, both emergency medicine physicians and radiologists performed better using the original films than the teleradiology workstation. The results also indicate that the accuracy of initial film readings by emergency physicians can be improved by radiologists' consultation, either by film interpretation or at a remote site on a teleradiology workstation.

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User-Specific Interfaces for Image Display: An Object-Oriented Approach

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1 INTRODUCTION

On-line radiologic image data is becoming more readily available to non-radiologists throughout the hospital for purposes other than primary diagnosis. Physicians, nurses, technicians and students are increasingly requiring access to radiological images for tasks such as review and teaching. Although all of these groups utilize the same information, the presentation and operations provided by the interface must be different to adequately support their diverse tasks.

The diversity in end-user requirements can impose a large burden on image management and communications systems designers if they are allowed to propagate throughout the entire system. At the University of Arizona we have designed and implemented a Medical Image Access System which provides access to digital radiologic images obtained from two Fuji Medical Systems U.S.A. (Stamford, CN) Computed Radiography (CR) machines. Images are made available to end-users in two intensive care units within minutes of the completion of the processing of the imaging plate by the CR unit. These images are suitable for *clinical review* tasks by ICU personnel primarily concerning verification of tube and line placement. This task is much different than the task of a Radiologist using images for *primary diagnosis*. Acceptance of the system by the end-users is very dependent on the ease of use and ease of learning. The design of the user interface based on task requirements greatly enhances the acceptance of the system by end users. However, a CR unit connected to a high-speed computer network is a very valuable resource. Therefore, it is important that the particular end-users task requirements are decoupled from the operations and architecture of the rest of the system. This will allow other end-user applications to be easily added to the complete system without significant modification, enabling the use of the valuable imaging resource by multiple end-users. In addition, it allows a high-degree of reuse of software for different end-user image access systems.

To achieve this decoupling of end-user tasks and the underlying image management and communications system we have developed the ICU application module (MIAS/ICU) based on the object-oriented paradigm [MAL93]. In this paradigm we decompose a system according to key abstractions in the problem domain, using the

vocabulary of the problem domain [BOO94]. This paradigm separates information architecture from the task for which the information is being used. This design method allows the easy development of task interfaces appropriate for different users while allowing the underlying common elements of their tasks to be implemented using reusable software.

2 MIAS/ICU IMAGE DISPLAY SUBSYSTEM ARCHITECTURE

The image display subsystem provides end-users with access to images in a task oriented manner. This means that the behavior of the interface, including the operations provided by the interface, is appropriate and intuitive in their support for the task for which the end-user is accessing the images. The task related interface behavior is decoupled from common image management and communications behaviors which are non-task specific. To accomplish this decoupling four primary classes of objects are used to implement the subsystem. These are:

1. Task - This class manages the data and functions necessary to provide system behaviors supporting a particular task. Collaborates with the other classes to get the necessary information and then controls the formatting and presentation of that data as appropriate for the task.
2. Census - This class manages information about the patients in the unit served by the display system.
3. Patient - This class manages information about individual patients.
4. Exam - This class manages information about patient images.
5. Report - This class provides patient report data and manipulation.
6. Image - This class provides image data and manipulation.

These classes arise from an object-oriented analysis of the problem domain ICU image related tasks. The relationships among these classes of objects are illustrated in a simplified class diagram Figure 2.1 below (following Booch's notation [BOO94]).

To implement a task interface we instantiate objects from classes which are derived from the problem domain model. These objects provide the behaviors attributed to each class and collaborate to provide the system behavior which supports the task. The simplified object diagram in Figure 2.2 illustrates the objects which implement a task and the links connecting them. In addition to the classes from the problem domain analysis, some additional objects are used to provide platform specific support. In the MIAS/ICU display subsystem these platform specific objects are instantiated from class utilities which provide support for the graphical interface and network communications.

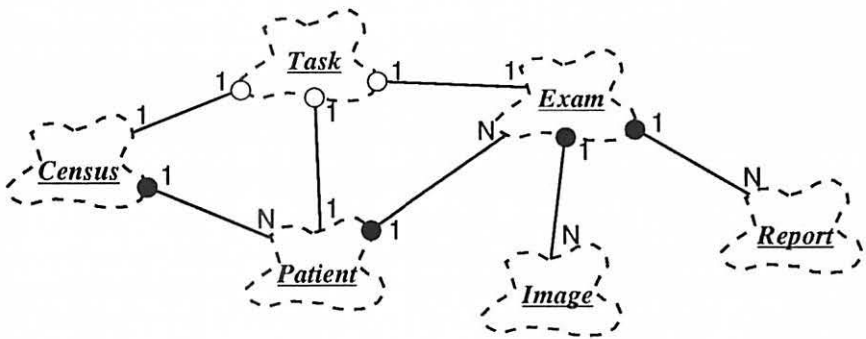


Figure 2.1 Objects in the Problem Domain

The X-Windows API (Applications Programming Interface) class utilities provide services necessary for interaction with the platform specific display and input hardware. The Data Comm and Image Comm class utilities provide services related network transfer of non-image and image data, respectively.

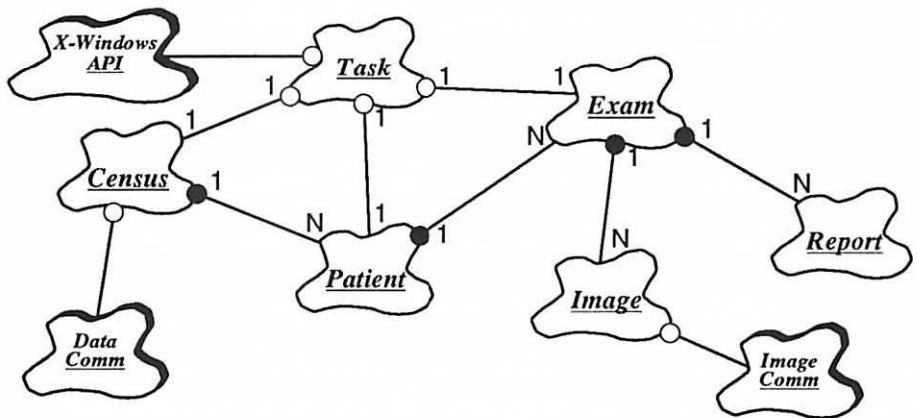


Figure 2.2 Objects in the Solution Domain

3 BENEFITS OF THE ARCHITECTURE

This architecture isolates task specific behaviors in the Task class and allows easy generation of new task interfaces by changing the type of Task object instantiated. In addition, isolating platform specific operations in class utilities allows the easy porting of the Task and supporting classes to new platforms. This portability has been tested by porting the display subsystem software from the current DEC 3000/400 AXP platform (under OSF-1) to other platforms and operating systems. A port to a DECstation 5000

(under ULTRIX) was accomplished by simply recompiling the source code. A port to an IBM RS6000 (under AIX) required only a minor change in a reference to a system library and was done in less than one day. Changes to the behavior of the user interface are easily accomplished by modifying only the Task object.

4 FUTURE WORK

Additional work related to this design will be the addition of a Task Editor class. It is anticipated that this class will enable the construction of new subclasses of the Task class by end-users themselves. Another modification will be the addition of classes related to multi-media information presentation to support text and voice annotation of images and appropriate modification to the task interface to allow access to these objects.

A current project is under consideration to develop a MIAS application module for providing radiological image access in the Emergency Department. It is clear that the image related task requirements will be significantly different, however most of the underlying image management and communications functions will be common to the existing system. This will allow rapid development of the display subsystems for the new application.

ACKNOWLEDGEMENTS

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Design and Implementation of a Telemedicine Workstation Using a Relational Database

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Introduction

Physicians are dependent upon visualizing patients or patient specimens such as biopsies or x-rays for diagnosis of disease. Pathology and radiology are two medical specialties in which imaging plays a central role. Static and dynamic imaging represents ways to address the problem of distribution of these specialty services, and to provide primary diagnostic services to rural clinics [8]. The following paragraphs discuss some telemedicine experiments and applications.

The concept of remote consultation and diagnosis is not new to telemedicine [6]. Medical diagnostic equipment produce digital image data from various sources including ultra-sound, Plain film (x-ray), computer tomography, nuclear medicine positron emissions tomography (PET), and magnetic resonance imaging (MRI). Picture Archiving and Communications System (PACS) were developed to archive, transmit, and display this kind of data [4]. PACS components include imaging equipment, viewing workstation, and a high-speed digital network.

Another area of telemedicine research is telepathology. Several experiments have been conducted in telepathology using analog microwave and satellite systems [9]. These systems transmitted live video images and voice over long distances via the satellite links. NTSC television image resolution was used, and was deemed to be of acceptable quality for the purpose of pre-operative diagnosis. One example of a telepathology system is a remote control microscope that is controlled by a workstation that is not at the same location [2]. The remotely located pathologist is able to zoom, focus, and pan the specimen.

A static telepathology system can be thought of as a video-fax, where static images are captured with a frame grabber and stored in a local database. Later the images can be transmitted non-realtime to a consultant. The static telepathology system may be part of a local area network at an institution, but may rely on a point-to-point communication system to transmit data to an off-site location. An example of a commercial telepathology system is the Roche Image Analysis System. The Roche system is a PC based system that includes a color video camera, a microscope, and a high-speed modem to provide image capture, transmission, and the remote consultation function [7]. The Roche system using Microsoft Windows operating system with proprietary software to process, and archive the image data.

Objective

The objective of this project was to design, implement, and demonstrate a PC based telemedicine workstation with image archiving and point-to-point communications system through the use of integrated custom and commercial applications. The telemedicine workstation (TMWS), should be applicable to several diagnostic services such as teleradiology, telepathology, and telemammography. In this paper, the emphasis is on telepathology, and low resolution radiology. The system will have a graphical user interface (GUI) from which the user can select a function for image entry, image display, database search, record maintenance, and file transfer. Along with the image data will be the pertinent text data and a comment field that can contain the physician's diagnosis. The potential of the personal computer and commercial software in telemedicine applications will be investigated to determine its strengths and weaknesses in the telemedicine environment.

Approach

The overall approach for this project was a software development effort using commercial software packages that integrate the system components into a multi-service telemedicine workstation. The system design is based upon past work in teleradiology and telepathology. The software for the PC based system used off-the-shelf programs where possible to provide an open system for future growth at a lower cost. At the outset of the project, software packages were investigated for their ability to handle image data, to be customized, and to operate in an integrated environment. After the software was selected, a top level design was generated based upon information from user scenarios that specified the functional components of the system. The system consists of four parts: the user-interface, the image viewer, the database, and the communication application. All four will be contained on a single personal computer. The following paragraphs provide a functional descriptions of each of the system components.

The user interface will use Microsoft Windows due to its ubiquitous nature, familiarity to most computer users, and its ability to integrate separate application into a compound application. The user interface is the main application from which all system functions are controlled. A custom control is created for each system function that when selected activates the function. A help utility is included to clarify functions, and when necessary the format of user input.

The viewer application presents the image data to the user. The viewer supports many image formats including GIF and Windows BMP bitmap format. Multiple image sizes are supported in a viewing window through the use of slide controls for image panning.

The database stores both the image data and the text data. The database functions searching, browsing, reporting, and data display are controlled by the user interface. The database locks records when in edit mode and posts the changes when

the user is finished editing. The database can function as a stand alone system or can be networked based with data access rights and shared and private data areas that provide data security.

The communication component will be a subfunction of the workstation system. User initiated image transfer as well as unattended remote communication functions will be provided. A simple Email facility is included in the communication function to allow remote sites to leave requests when the telemedicine system is unattended. Multiple level password access provides some system security. The communication function supports common transfer protocols, and variable transfer rates with no loss of image data. Although network scenarios will be discussed, for the demonstration system communications to remote workstations will be point-to-point system performed via high speed modems. In addition, the data rates of transfer protocols are tested and results presented.

Implementation of System Software

The foundation for the project software is off-the-shelf or commercial database and communication programs. Each were chosen based on past project experience or reported features and performance. Of primary importance in the selection is the capability for inter-application communication and extensibility of the base product.

Borland's Paradox for Windows is the Microsoft Windows version of the successful DOS based program of the same name. The inclusion of Binary Large OBject (BLOB), Dynamic Data Exchange (DDE), Object Linking and Embedding (OLE) data types, and network support motivated the selection. Paradox also includes a robust object oriented programming environment that allows the development of custom applications.

The communication package selected in Procomm Plus for Windows (for simplicity Procomm). Procomm supports the DDE protocol that accepts remote commands from another application. Also, an application development language called Aspect permits the generation of user-friendly programs based on Procomm's functions.

A fundamental design criteria of this project is to create a image management system with extensive use of off-the-shelf software. To achieve this goal the integration of the system software components is essential. Windows has two methods of application integration [4,5]. The first is Dynamic Data Exchange (DDE), and the second is Object Linking and Embedding (OLE). OLE, sometimes pronounced Ole', is a superset of DDE and was introduced in version 3.1 of Microsoft Windows. OLE and DDE function to manage linked or embedded data objects between applications. Through the use of OLE and DDE, Windows applications can be integrated to take advantage of the resources of each software package.

Results

The following paragraphs present a summary of the resulting telemedicine system.

Telemedicine Selection Screen

The Telemedicine selection screen allows the user a choice of selecting a database for viewing or operation of the communication functions. Figure 1 shows the selection screen with a graphical representation of a radiology and a pathology image to highlight the purpose of the database application.

ImageBase Main Form

Figure 2 shows the main form. The main form is the first screen that the user encounters when starting the telemedicine application. From this screen the user can view the image and text data, browse the database, and invoke several system functions. These include data entry, find, printing of a pre-formatted report, the image export function, image zoom, and the transfer function. The window surrounding the form is in a Microsoft Windows standard format with sizing controls, title bar on top, message bar on bottom, and a menu bar. The key features of the form are the function buttons, drop-down menu bar, image field, data field, and the record control buttons. The image field has sliders, which are built-in properties of a graphic field assigned during design, to allow panning of images too large to fit in the viewing area. The data area presents a concise representation of the accompanying text. The comment field within the data area does word-wrap, and has a scroll bar to accommodate text entries larger than the area shown.

The Transfer button initiates a dialog box that gives the users a choice of initiating or hosting a communication session. Each button performs a DDE Execute command that activates the communication application Procomm. It also, in the same execute command, runs either the Call script, or Host mode script in Procomm. The Call facility provide automated connection to a remote workstation, and the Host script allows unattended remote access from a remote workstation. These functions are sufficiently automated to shield the user from the underlining connection and data transfer functions.

As part of communication testing, a test was performed to determine the transfer rate of the Kermit and Zmodem Protocols over normal condition telephone lines. The test system consisted of two PC compatible computers using 14.4 kbps modems. The sending computer was placed in Host mode, and the receiving computer initiated all of the transfers maintaining a log of the transfer times and the transfer rate in characters per second. The test data shows that Zmodem protocol is greater than two times faster than the Kermit protocol under the given test conditions.

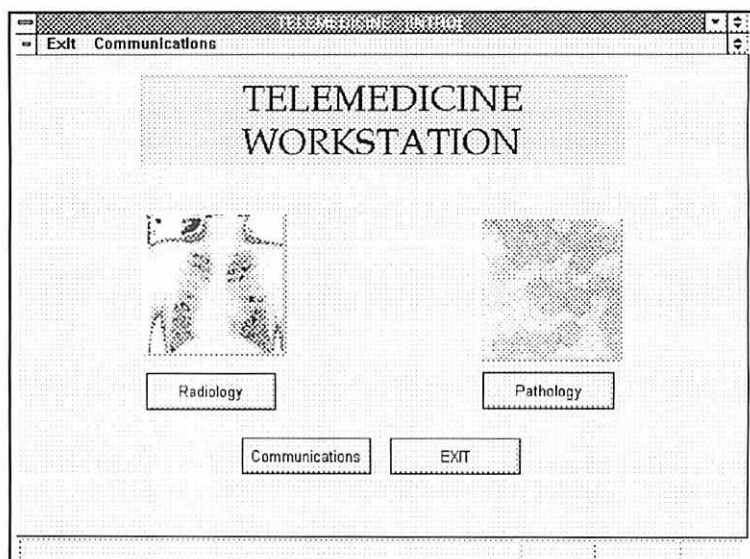


Figure 1 Telemedicine Selection Screen

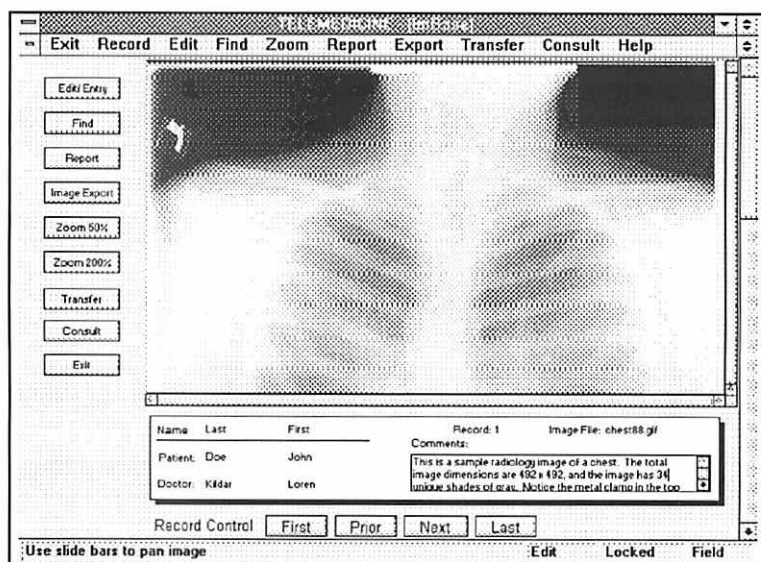


Figure 2 Telemedicine Main Form

The main emphasis in the file transfer testing has been on using high-speed modems with and without file and hardware compression. To understand the impact of using a point-to-point system it is useful to compare the results of the modem file transfer times with that of an ethernet file transfer. The following data in Table 1 is an excerpt of [10] which tested 14400bps modem and Ethernet transfers on a pathology images. Image file size used for comparison were chosen to span a range that include those tested in this project. The Ethernet transfer times are representative of the image storage and retrieval of a network Paradox based telemedicine workstation.

Table 1 Transmission Time of 14.4Kbps Modem and 10 Mbps Ethernet

Image Size in Bytes	14400 bps Transfer Time	10 Mbps Ethernet Transfer Time
46584	31.52 seconds	0.79 seconds
75072	48.67	1.17
138582	86.80	1.72
192618	119.64	2.35
319104	194.62	3.93
360894	219.96	4.12

Summary and Conclusions

This project has demonstrated that PC compatible computers, and applications based on commercial software can be used in telemedicine. The demonstration was accomplished by realizing a graphical database and communication systems using integrated off-the-shelf software. The Paradox database ObjectPal development language allows custom user interfaces to be created that simplified the system interface. Microsoft's Windows environment integrates the database functions with Procomm Plus, and the image viewer. The windows environment and applications selected proved be extensible and flexible enough to be of value in telemedicine applications.

Future Work

The flexibility of the Windows environment and Paradox provide wide ranging possibilities for enhancement of a PC based telemedicine system. The following paragraphs will discuss some possible scenarios.

Multimedia Workstation

A PC multimedia workstation will have a CD-ROM drive, and an audio system in addition to the enhanced workstation characteristics discussed previously. The multimedia capabilities enable the database system through OLE to record and play back a voice file stored in the database record. In addition, short video samples could be included as part of the record, or could be linked with data on a CD-ROM. Integrating the multimedia features will provide an excellent instructional tool as well as professional environment.

Integrated Remote Consultation

Using Windows object linking and embedding (OLE), a custom image viewer could be linked to the database function. The image viewer would include file transfer and remote consultation functions. The image viewer would become the primary working area for the operator. The database functions would be used only for storing and manipulating the image data. The viewer functions could also include image annotation for highlighting areas of interest on the subject image. The video multimedia features could be used to record portions of the remote consultation session for play back at a later time.

Implementation of Network Based System

The Paradox database includes functions for network support. A image database system using a local area network or a peer-to-peer network can be implemented using demonstrated concepts presented in this project. The network function can, as previously discussed, work with the point-to-point system to connect remote sites. A networked PC based system could also work with other imaging systems as a supplement. Further research into the networking of a PC based system could involve the Internet for data transfer.

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The American Board of Radiology's Self-Evaluation Workstation Project

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I. INTRODUCTION

For the past year, the American Board of Radiology (ABR) has been developing a self-evaluation computer workstation for radiologists, for presentation of cases, questions related to the cases, and associated images. The motivation for this project has been to explore its feasibility to meet future testing needs of the ABR, such as certification for advanced qualification in certain subspecialty areas, and should it be required, recertification of practicing radiologists. A goal is to provide examination capabilities at regional or local sites, in privacy, and with less subjectivity than current oral examinations. They may also be used as an adjunct to the oral examination.

The National Board of Medical Examiners [1] has explored computer-based examination for many years. Various medical specialty boards are now also doing so, most of which use a case-based or problem-oriented approach to examination. Although until recently none of the programs had directly incorporated multimedia content with the examination, several boards are now exploring this. Complementary projects aimed at student education and CME using case-based problem solving paradigms have seen considerable development [2-5]. A number of educational and testing activities have used videodisc images, with and without computer control.

Features desired by the ABR were: (1) all-digital media for highest image resolution and flexible manipulation; (2) exam customization based on specialty areas and experience level; (3) collection and analysis of data on usage; and (4) random selection of questions. The workstation needed to demonstrate flexibility, user acceptability, and ease of use. A request for proposals was issued by the ABR in 1992, and a contract was given to the Decision Systems Group (DSG), Brigham and Women's Hospital, to implement a prototype system with these features for evaluation by the ABR and by practicing radiologists during 1993.

II. METHODS

Implementation of the workstation by the DSG involved two parallel activities involving (a) content acquisition and (b) software development.

(a) *The content acquisition activity* was concerned with database management, and image digitization and processing. A database of cases, questions, and associated

images was established. Content was acquired in the ten radiologic areas evaluated by the ABR, and in the area of radiation oncology. Questions were all designed to be of the multiple choice/single answer type. The database contained approximately 160 cases, with images and questions (averaging approximately 15 per area) provided by members of the ABR. Content acquisition involved the collaboration of radiologists from around the U.S. for collection of static and dynamic images and question content.

Most images used in the project were scanned directly from first or second generation plain films, using a Konica KFDR-S Laser Scanner, with an 85–170 μ step size (depending on image size) and 170 μ aperture. Images were further processed with NIH Image and Adobe PhotoShop software packages. Image processing consisted of cropping, brightness and contrast adjustment, initial size determination, and artifact removal. Some images were acquired directly in digital form. The final stage of processing consisted of converting each image from TIFF to ZOOM format. ZOOM format images, which contain multiple resolutions in a single file, were created through the use of a custom plug-in filter we developed for PhotoShop, and are required for use with a special imaging tool we have developed [6] that provides capabilities for selective and global magnification, panning, brightness and contrast manipulation, local "bright-lighting", and image annotation.

Once images have been optimized for viewing, they are assembled into cases with the aid of the DeSyGNER authoring system [7], a hypermedia presentation tool of the Decision Systems Group, which supports manipulation of images and management of multi-image screen panels.

(b) The software development activity consisted of providing mechanisms for displaying questions and images, based on user profiles and areas of interest, and of accepting and tracking user responses. The image display functions of the workstation project were performed by the DeSyGNER tools, which support a variety of image manipulation and viewing capabilities. The image display component of the workstation was integrated (through the use of messaging via AppleEvents) with a main control panel, which were written in Aldus SuperCard. SuperCard, enhanced through XCMD extensions developed in C and Pascal, provided the main user interface for the workstation, and served as the database engine for questions and feedback.

The workstation was implemented for the Macintosh computer, with the intended configuration being a Quadra 800 (Apple Computer, Inc.), using a 20" high resolution monitor and with a graphics card supporting 24-bit color and hardware acceleration.

The program was previewed by the ABR at its meeting in November, 1993. To evaluate radiologist ease of use and acceptance of a computer-based examination, the program was made available to attendees at the 1993 RSNA meeting, November 27 through December 3, 1993. This was carried out in the InfoRAD section of RSNA during the 5-1/2 days of the meeting.

Each user was asked to complete a short user profile indicating (a) specialty areas of interest, (b) practice setting, and (c) number of years of medical experience. Five questions were then randomly selected by the program from the specialty areas selected,

and the user was asked these questions sequentially. Brief feedback about the correct answer to each question was provided after the user's answer was given. Tracking data on user performance per question were stored. Following the entire set of five questions by each user, a summary score was provided for all questions answered, and for each specialty area included.

After completion of the questions, each user was also asked four survey questions, each on a 5-point scale (high to low): (a) extent of computer experience, (b) ease of use of program, (c) quality of images, and (d) appropriateness of questions.

III. RESULTS

Features of the user interface, as shown in Fig. 1, are: (a) a question and multiple choice answer area at the bottom, (b) a set of thumbnails indicating images available for the case, at the right, and (c) a viewing area involving most of the screen, in the upper left; in the latter area, full size images in multiple windows, corresponding to the thumbnail images, can be viewed and manipulated. Each image panel has a variety of icon controls for roving magnification, zoom, pan, brightness/contrast manipulation, and "brightlight".

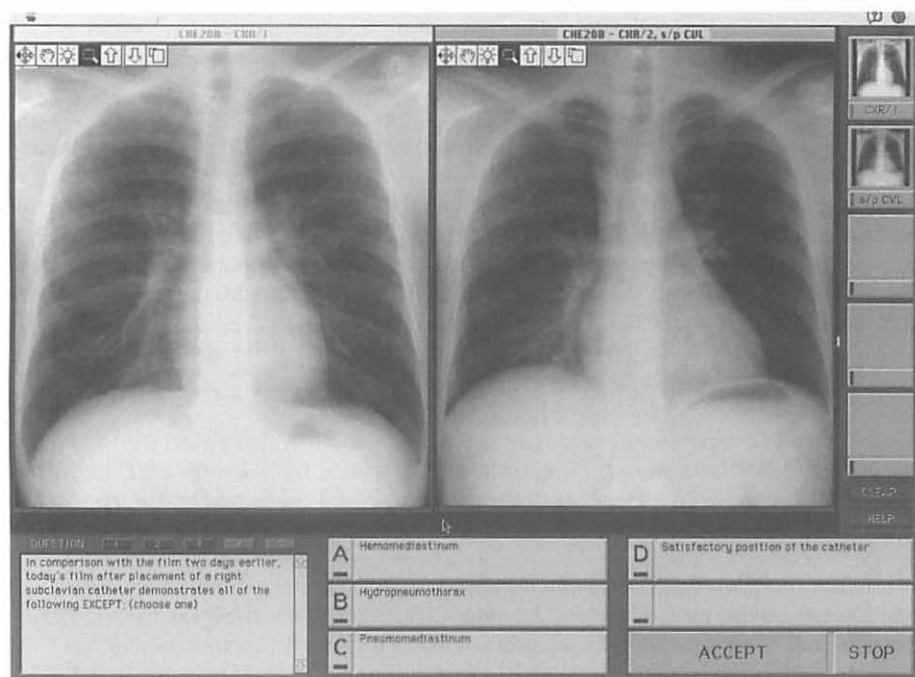


Fig. 1 An example of the user interface

We analyzed the user profiles, performance in the various specialty areas, and attitude surveys, from the data collected during the RSNA week. User profile and performance analyses reflect the 1,108 individuals who answered radiologic imaging ques-

tions. Of these, 531 individuals completed the attitude survey at the end. Thus, survey results are based on this smaller sample.

Of 1108 users, 86% selected one primary specialty area, 6% selected two areas, and 4% selected three areas, in which to be evaluated. The most frequently selected area was Chest (by almost 25% of users), followed in decreasing frequency by mammography, neuroradiology, gastrointestinal, cardiovascular, and musculoskeletal, and less frequently by other areas. Years of medical experience were: 0-5 years 31%, 6-10 years 35%, 11-15 years 11%, 16-20 years 10%, with smaller numbers in categories >20 years. Practice settings were: private 40%, academic 32%, resident 13%, fellow 8%, medical student 4%, and other 3%.

The following questions were rated on a 5-point scale, from highest=1 to lowest=5. Percent responses in each category are shown

<u>Category</u>	Highest <i>Response</i>	1	2	3	4	Lowest 5
Computer experience	13	23	23	21	20	
Ease of use of program	28	41	21	8	2	
Image quality	26	42	22	9	1	
Question appropriateness	22	41	25	9	3	

Most users found the program easy to use, regardless of prior computer experience, as shown in Fig. 2.

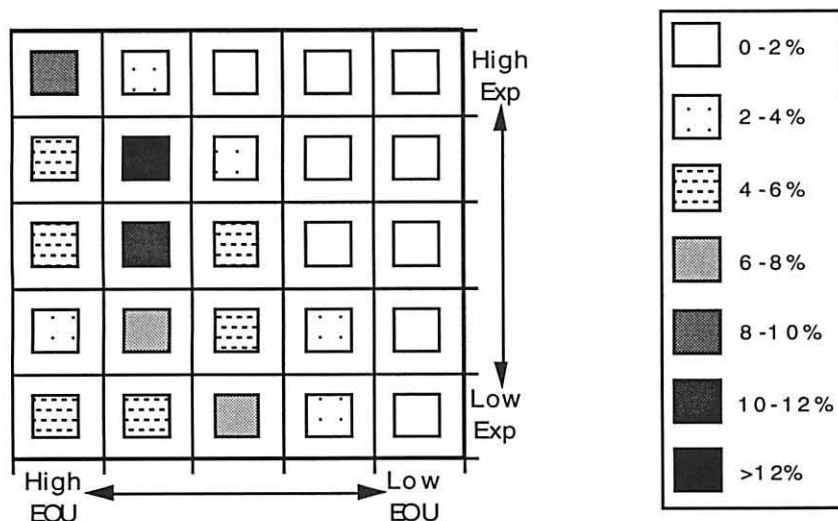


Fig. 2 Ease of use vs. prior computer experience

Users with limited computer experience tended to limit their interaction to basic operations of the program. As experience increased, more experimentation by the users

was done, and users were more likely to try the various imaging controls, e.g., to manipulate the brightness and contrast or use the zoom and pan controls. While the use of these options was somewhat easier for the more experienced users, it did not appear that their availability impeded the less experienced users to a great extent.

Another crosstabulation showed that the highest number of users in all practice settings reported moderate to low computer experience. As expected, a higher relative percentage of those in academic practice settings reported greater computer experience than those in private practice or other practice settings. Assessment of ease of use was largely independent of prior medical experience, practice setting, or age.

A Help menu and a posterboard sign describing program options and image manipulation controls were available at each workstation. Anecdotally, we noted that very few individuals used either of these. Most were able to use the program readily following a brief introduction by the staff persons who were available, whether the individuals had prior computer experience or not. Considerable spontaneous, positive commentary was received about the image quality and about availability of the tools for brightness and contrast manipulation and zoom magnification. A helpful suggestion made by several users was that radiologists be allowed to indicate areas in which they wished to be questioned separately from indicating their areas of specialization, since these do not always correspond. Further, it was recommended that a category of clinical practice and area for questioning called "General" be provided.

User performance was analyzed as a function of specialty area and overall. Questions in most subject areas had a wide spread of answers, suggesting that they were at an appropriate level of difficulty, with the modal number correct being 3 questions out of the 5 that were asked per user. Primary exceptions were in cardiovascular/interventional and radiation oncology, which appeared to have more difficult questions. Average time per question was 1:12 min $\pm$ 0:54, with a range of (0:12 - 6:04).

IV. DISCUSSION

Our overall conclusion from the RSNA evaluation was that the program was a definite success. Over 1,100 radiologists used the program during the week. Most commentary was highly favorable. Many individuals expressed the desire (sometimes coming back repeatedly to make the point) that a program in this form be made available for CME.

Specific conclusions were that: (1) The program's format, ease of use, and image quality are highly acceptable to radiologists. (2) Desire for a program of this type for CME is strong. The implication is that examination in this format would also be acceptable, especially if individuals have prior opportunity to use similar programs for self-study. (3) The assessment identified several user interface and performance improvements that can be made. These are all minor and easily accomplished.

ACKNOWLEDGMENT. Introduction of the program to radiologists at the RSNA meeting was aided substantially through the excellent assistance and support of the RSNA. The cooperation of the members of the ABR in supplying cases and offering helpful commentary is greatly appreciated.

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Tissue Segmentation with PC-Based Multiparameter Full-Color Composite Display: Application in MR Imaging of a Patient with Glioblastoma Multiforme

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INTRODUCTION

Recent advances in computer graphics hardware now allow full-color image processing to be performed at the personal computer (PC) level. A PC-based image processing technique has been utilized to generate full-color composites from multiparameter MR images using the red-green-blue (RGB) color model [1]. We have applied a similar technique to MR images of a patient with glioblastoma multiforme to generate composite images for tissue segmentation, and have correlated the results with post-mortem pathologic findings.

METHODS

The patient in this study is a 48 year old female who was diagnosed with glioblastoma multiforme involving the left posterior temporal lobe following a craniotomy with tissue biopsy 22 months earlier. When she began to experience worsening neurologic symptoms, the MR scan of the brain in this study was obtained. The patient expired thirteen days later, and an autopsy was performed the next day.

MR Imaging:

This study was performed in accordance with Institutional Review Board regulations for research protocols involving human subjects. Imaging was performed on a 1.5-tesla General Electric Signa Advantage MR imager (General Electric, Medical Systems Group, Milwaukee, WI). Initially, transverse T1-weighted, proton density, and T2-weighted MR images were acquired. Following the intravenous administration of gadolinium, transverse T1-weighted, proton density, and T2-weighted MR images were obtained (Figure 1).

Color Image Processing and Analysis:

From the image data acquired, selected sets were transferred via diskette to a high performance PC with a 386 microprocessor and a 24-bit ATVista video graphics adapter card (True Vision, Indianapolis, IN). Image data files were converted to TARGA format for display on a high-resolution Mitsubishi Diamond Scan color VGA monitor (Mitsubishi Electric, Nagasaki, Japan). Image analysis studies and processing routines were performed using Image-Pro Color Image Processing System Software Version 2.0 (Media Cybernetics, Silver Spring, MD) and custom image composition software.

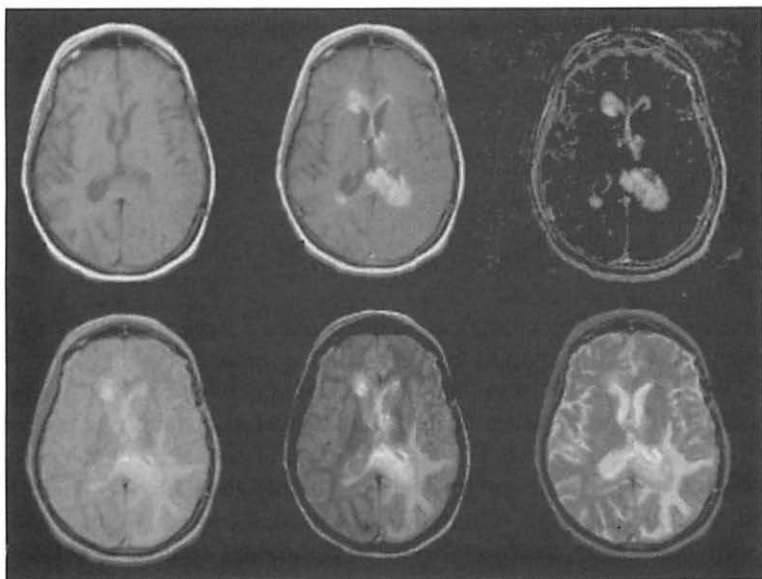


Figure 1. Gray scale MR images used to generate the full-color composite in Figure 2.

Image processing routines included the creation of a subtraction image depicting only gadolinium-enhanced tissues (Figure 1, top right). This image was generated by subtracting the pre-gadolinium T1-weighted image from the post-gadolinium T1-weighted image. A contrast-enhanced proton density image was also created (Figure 1, bottom middle). Due to significant motion artifact, the pre-gadolinium proton density and T2-weighted MR images were not used for composite generation. For each component image within a multiparameter set, color masks were selected by assigning a percentage value for each respective RGB channel, with 0% specifying no contribution (intensity level of 0) and 100% specifying full intensity (intensity level of 255) for the color channel indicated. The color-masked MR images were then arithmetically combined using the additive RGB color model to form single color composite images with a full-color display palette of over 16.7 million possible colors.

Color image analysis was performed using the Image-Pro software to

determine the mean and standard deviation values of each RGB channel in various tissue regions of interest (ROIs) from each composite in a five image set. These ROIs were compared using 95% confidence intervals (CI) of the mean R, G, or B channel value plus or minus twice its standard deviation in order to assess for segmentation based on separation of at least one color channel (no overlap of 95% CI).

Autopsy and Histologic Slide Preparation:

Following removal of the gross brain and spinal cord, the brain was sliced into horizontal sections at 5 to 6 mm intervals approximating the transverse MR scanning plane. Tissue specimens were sampled from various brain sections, and prepared for hematoxylin and eosin (H&E) staining using standard procedures. Findings on gross anatomic and histopathologic examination of the specimens were correlated with the MR findings.

RESULTS

MR Imaging and Pathologic Correlation:

Examination of gross brain sections revealed a large irregularly shaped mass located in the deep left temporal lobe and extending around the left posterior horn of the lateral ventricle. Comparison with the gadolinium-enhanced MR images and the corresponding color composites demonstrated good correlation with the grossly visualized tumor extent as well as additional areas of enhanced tumor not visible in the gross specimens. The original diagnosis of glioblastoma multiforme was confirmed by examination of selected H&E-stained sections. Comparison of post-mortem histologic tissue specimens with the composites confirmed the histology of the various color-mapped tissues. A representative color composite appears in Figure 2.

Color Image Analysis:

From the five composites generated, color image analysis of RGB channel data revealed separation of tissue ROIs on at least one channel for most tissues tested using a 95% CI. These tissue ROIs included cerebrospinal fluid, gadolinium-enhanced tumor, brain white matter, brain gray matter, muscle, and subcutaneous fat. Overlap of CIs did occur between some non-adjacent areas of white and gray matter within two of the five images tested.



Figure 2. Multiparameter full-color composite image demonstrating areas of magenta-colored tumor enhancement. White matter appears a dark gray-brown, gray matter appears a reddish brown, CSF is blue-green, white matter edema is a brownish blue-green, muscle is brick-red, and subcutaneous fat is flesh-colored.

DISCUSSION

In multiparameter composites, each colored pixel is defined by three coordinates within a cubic Cartesian coordinate system representation of the RGB color model. This color cube possesses x, y, and z axes corresponding to integer R, B, and G color channel values ranging from 0 to 255. Within the RGB model, each unique color can also be represented as a vector which takes its origin at the coordinates 0,0,0 and terminates within the cube at its color-defining RGB coordinates [2]. Since like-colored pixels will cluster within similar regions in color space, any significant difference on any one color channel will automatically segment the mean vector representing a specific tissue ROI into a unique region within the RGB color cube [3].

An advantage of the methods presented in this report is the simple arithmetic approach used for tissue segmentation. The basic addition of corresponding pixels within color-masked image sets allows real-time automatic tissue segmentation to be performed at the PC-level within a matter of seconds for each composite generated. Moreover, the inevitable introduction of faster, higher capacity microprocessors at the PC-level will allow for an even greater expansion of the image processing capabilities of these systems, including lower cost full-color three-dimensional medical imaging applications currently performed almost exclusively with higher cost dedicated systems.

Since this method requires spatially aligned multiparameter MR image sets for accurate composite pixel color assignments, patient movement both during and between different pulse sequence acquisitions represents a potential problem for image data accuracy. In addition, overlap of important tissue color assignments can occur within a given image, although various statistical classification strategies can be applied for segmenting pixels within overlapping ROIs [3]. However, it should be noted that while color tissue maps can differentially present the bulk tumor mass, computer-defined edges do not necessarily represent definitive tumor borders as histopathologic correlation of gadolinium-enhanced MR images with brain biopsy specimens has revealed the presence of neoplastic cells in non-enhancing areas of surrounding edema [4].

In this report, we have described the application of a PC-based full-color composite display technique to multiparameter gray scale MR images obtained from a patient with glioblastoma multiforme. Color analysis of the RGB color channels of tissue ROIs has demonstrated that this digital image processing technique can differentially segment various anatomic and histologically-confirmed tissue types within each composite into unique regions within the full-color spectrum. Based on the results achieved in this study, full-color composite display represents a viable technique for achieving automatic tissue segmentation, and may be a feasible method for summarizing the diverse tissue contrast information present within multiparameter MR images.

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SESSION 14

Information Systems

Chair: Ronald L. Arenson

Data Transfer from a Radiology Information System to a Personal Computer Network Using a Configurable Software Multiplexer and HL-7 Protocols

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ABSTRACT

We investigate a method for increasing the utility of a radiology information system (RIS) by connecting the RIS to a personal computer network and transferring radiologic data to a more user-friendly, familiar computing environment. This is accomplished with a configurable software multiplexer that receives HL-7 messages from our RIS and routes them to different destinations based on information included within each message.

INTRODUCTION

Many different approaches to connecting a RIS to other computer systems have been used, and many problems have been encountered.¹⁻⁵ Most significantly, the lack of a bidirectional interface has proven to be a major limitation.⁶ While the HL-7 protocol⁷⁻⁸ is not yet at the level of a standard which can be used to connect two arbitrary computer systems without some software modification, it serves an excellent basis on which to build an interface. Once the data have been moved to a personal computing environment, users have access to a broad range of software tools to manage, process, and display the information for teaching, research, or administrative purposes.

METHODS

We have developed a personal-computer local-area network which is linked to our RIS. Our software continually transfers data -- including radiologic interpretations and associated demographics -- in real time from the RIS to a file server on our network which supports cross-platform access for Macintosh and IBM PC-compatible computers. Data are stored in a format compatible with inexpensive, personal-computer database software. Thus, radiologists can use their preferred hardware and software to search this information, extract data and store it locally for research purposes, and share data on-line as they collaborate with other investigators.

Our RIS resides on a VAX minicomputer running the VMS operating system. Although our RIS provides several protocols for importing or exporting data, there are no software tools accompanying the RIS to facilitate the programmer's task of implementing these protocols external to the RIS, especially with respect to quasi real-time data exchange. We believe that a powerful software tool for this purpose is essential for facilitating clinical research. Consequently, we have developed a data-exchange tool which uses an HL-7 dialog between locally developed VMS-based software and our RIS. Our software, conceptually speaking, is a configurable multiplexer. Via simple configuration variables, HL-7 messages that contain information about finalized radiologic examinations are routed to specific destinations on our LAN file server. The information transferred includes the text of the radiologic report. Up to 16 different destinations can be concurrently active. We assign a destination based on the type of radiologic examination (i.e., exam code) and the equipment used (i.e., resource) for the examination. Thus, reports for all CT scans, ultrasound examinations, and MRI studies of the abdomen are routed to one destination. Likewise for cross-sectional thoracic examinations, and for interventional procedures, etc. Each destination, in the context of our file server's environment, represents a continually updated file within a specific folder (if using a Macintosh) or directory (if using IBM-compatible).

This software is self-sustained, running as a detached process on our VAX. There is a straightforward method for configuring its behavior using DEC Command Language (DCL) symbols. At any time, our end users can invoke a Foxpro application (Microsoft Corp, Redmond, WA) on their personal-computer platform to import the arrived messages into a clinical research database that is tailored to their specific area of interest.

RESULTS

These capabilities facilitate any research which requires a tailored, retrospective analysis of radiologic data. The need for ancillary personnel to perform paper-based searches or redundant data entry is decreased. Radiologists and administrators also have user-friendly access to information which might facilitate other projects dealing with education or analysis of clinical efficacy.

The wide applicability of this software meets the needs of several different department sections (e.g., chest radiology, abdominal radiology, neuroradiology). Each departmental section can work in their preferred computing environment (IBM-PC or Macintosh), continually update their own research databases, and use the same software for searching or manipulating the data.

Our software augments the data sharing features that are built into our RIS. No customizations of the RIS are necessary. We use the HL-7 protocol for communicating with the RIS. Thus, we anticipate no problems pertaining to upward-compatibility during version upgrades.

CONCLUSIONS

A software tool for transfer of data from a RIS to a personal computing environment is a valuable asset. This is particularly true for academic institutions. The ever-growing power of personal computers, combined with inexpensive yet sophisticated software for these machines, frequently provides a more useful method for retrospective analysis of radiologic data than a proprietary RIS running on a minicomputer. The RIS of the future will hopefully have more powerful options to analyze radiologic data and provide easy methods to transfer data to personal computers.

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Integrated RIS: Clinical Data Viewed from Different Perspectives

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1. Introduction

Most present day Radiology Information Systems focus on the support of the daily activities of radiodiagnostic departments. Most RIS-ses though are developed as stand-alone departmental systems, with limited communication with other information systems in the hospital. This may result in data not being used to their full extent, or multiple registrations of the same data. Furthermore, in the clinical process between request and report, much valuable data is registered in the RIS that could also be used for managerial, educational and research purposes. Still most present day RIS-ses fail to provide for these alternate views on clinical data.

BAZIS, the Central Development and Support Group HIS in the Netherlands has been involved in the development of a RIS called RADI, which is presently in use in 35 hospitals in the Netherlands. RADI functions as an integral part of the BAZIS Hospital Information System. BAZIS has been developing and implementing its HIS since 1972 and serves many Dutch hospitals, together over one third of the acute hospital beds in the country [1].

The strength of the BAZIS HIS lies in its philosophy of Integration: once-only registration of the data at the time and place it is generated, and presentation of the information when and where needed, in a lay-out suitable for the individual user. This means that recorded data is available to be used for different purposes (e.g. department management). Also, there is quite some information to be shared between the radiology department and other hospital departments. As the RIS and the other HIS subsystems can be both producers and requesters of data, integration of the RIS with the HIS is considered essential. Similarly the integration of PACS with the RIS and HIS is a topic of ongoing research and development. The latter will not be discussed in this paper.

This paper will first explain the basic functionality of the BAZIS RIS, focussing on the integration of the RIS with the HIS. Next it will discuss two examples of how clinical data of the RIS can be used for managerial, research and educational purposes.

2. Functions of a RIS integrated in a HIS

The BAZIS radiology information system RADI consists of several modules to meet the requirements of a complete RIS [2]. The modules are designed as one integrated whole but implementation can be stepwise and allows for a tailor made RIS:

- Nucleus : visit/request registration, printing of labels and worklists, archiving and review of historical data and reports, nuclear dosage registration, feeding of financial administration.
- Appointments : scheduling, reviewing, changing, cancelling of appointments
- File management : request and tracing of film folders, sending out reminders, worklists and maintenance for the film archive department.
- Patient tracking : following and directing the patients flow over the department
- Reporting : recording and managing radiology reports, communication of the reports to the referring specialist or GP
- Speech recognition : allowing for direct dictation by the radiologist into the computer by coupling with a speech recognition system
- Diagnoses coding : coding of radiodiagnostic findings, searching and reviewing for data related to certain findings
- Management info : providing managerial views on operational data.

The basic idea of once-only recording of patient data in the HIS, which then becomes available for users at other departments, allows for different views at the same data. Examples of data shared between multiple users within the radiology and with other hospital departments are personal patient data, insurance data, GP data, admission data, appointment data, previous lab results, radiology reports and OR reports, diagnoses, etc. The application of the philosophy of integration in the BAZIS RADI subsystem has lead to the following advantages [3]:

- Automatic tuning of the patient's radiology appointments with other appointments of the patient e.g. at the outpatient clinics; possibility for requesting and scheduling appointments by clinical departments.
- Decentralized requesting of film folders and tracing of folders throughout the entire hospital; printing of requests and reminders for film folders directly at the department where the folder is currently located.
- Automatic inclusion of data in the radiology reports, e.g. patient personal data, requester data, examination data, etc.; immediate printing of reports at the requesting department, immediate (electronic) communication of the report to the requesting GP.
- Immediate on-line review of results and reports by authorized personnel from the requesting departments.
- On-line review of the patient's medical data to support the radiologist in the diagnostic process (e.g. pathology and lab results)
- Financial administration and billing without the necessity of human interaction; one uniform and integrated bill to the patient and/or insurance company.
- One uniform environment for the user to access all required data and functions.

By recording the data only-once and allowing for users to view this data from different perspectives, efficient and effective support is given to the daily, operational, activities in the radiology department.

3. Using clinical data for department management

A RIS does not have to be limited to daily activities. After all, the RIS contains a great amount of operational data that can also be used for managerial purposes. Most RIS therefore provide a (limited) set of predefined reports. However, often small variations in the reports are desired, and users should have the possibilities to define their own reports [4]. With flexible and easy to use tools, the operational data can be transformed into valuable information and statistics on production, leadtimes, waiting times, work load calculations, referral patterns, etc.

In RADI, a great variety of production and process data has been recorded during the clinical proces, like: personal patient data, requester data, examination data, reporting data, procedural data, patient tracking data, personnel involved, etc. These data that are normally stored in the production data files are copied to a separate management data file. Because of its structure this management data file allows for an easy and fast access of the clinical data.

RADI then makes use of the general report generator of the BAZIS/HIS to perform operations like selection, sorting and printing of data. It is easy to combine the radiology data with data that is elsewhere recorded in the HIS like address of GP, description of radiological procedure, etc. Finally the system allows for all kinds of calculations like counting, percentages, cross tables and statistical operations.

To make life easier for the manager of the radiology department RADI provides a set of 27 predefined management queries. The manager can easily make adjustments to the query definitions, based on the actual needs for information of the department. It is also possible for the manager to define his own reports and queries from scratch.

To actually process the queries into a report, the system offers both a real-time (on-line) and a batch facility. For each query request RADI checks whether the user is authorized to process the query and to access the data used by the query.

When using the on-line facility, additional checks are done:

- is it allowed to run the query on-line or are there any other restrictions, like a query that can only be processed during the more quiet moments of the day (eg. before 10 am, during lunch break, after 4 pm).
- will the query not exceed a preset value of allowed load for on-line queries.

Still, most users find it suffices to have the queries processed during the night. It is also possible to define an interval after which batch queries will be processed automatically (eg. every week). To check whether a query will give the needed information, the system has a facility to test the query on-line using a limited data set.

Some examples of the reports that can be made:

- number of examinations performed per room
- age distribution of patients with a certain examination
- distribution of visits over days of the week, and over the day for each weekday
- variation in examination durations
- actual workload calculations for certain examinations (based on durations)
- overview of number and types of combinations of examinations
- patients without appointment during busiest hours of the day, sorted by requester
- reporting leadtimes per radiologist (from end-of-exam to date/time-of-authorization)
- punctuality of patients
- average waiting time for patients over the day
- number of patients waiting too long, per room and day of the week.

PATIENTS WITH AN APPOINTMENT WAITING TOO LONG (> 15 MIN)
PER ROOM AND PER WEEKDAY

	mo	tu	we	th	fr	total
B	-	-	-	-	-	0
H3	-	-	-	-	-	0
R1	-	-	1	-	1	2
R10	4	12	10	2	9	37
R11	-	1	-	-	-	1
R12	20	19	24	16	34	113
R13	1	-	1	1	1	4
R32	-	-	-	-	2	2
R35	8	15	16	18	16	73
R36	10	23	23	26	11	93
R39	2	5	5	3	1	16
R4	-	2	3	2	-	7
R7	2	1	-	3	1	7
R8	9	12	9	7	9	46
	56	90	92	78	85	401

Fig. 1 Example of RADI query output (based on 3 months production in a large university hospital)

The BAZIS/HIS has only limited graphical and statistical possibilities in comparison with the commercially available PC programs dedicated for this purpose. One might consider to download the operational data to a PC and carry out the management support functions on the PC. However these PC applications are often less suitable for processing very large databases (e.g. a large hospital may store over 1 million radiology visits), and it is not possible to combine the data on the PC with other data from the HIS (e.g. GP information for queries on referral patterns). Finally PC's have limited facilities for data management and access control. Therefore it was decided to maintain the management data base and process the queries at the HIS. In case there is a need for statistical analysis or graphical presentation, the aggregated results can automatically be transferred to a PC.

AVERAGE WAITING FOR PATIENTS OVER THE DAY

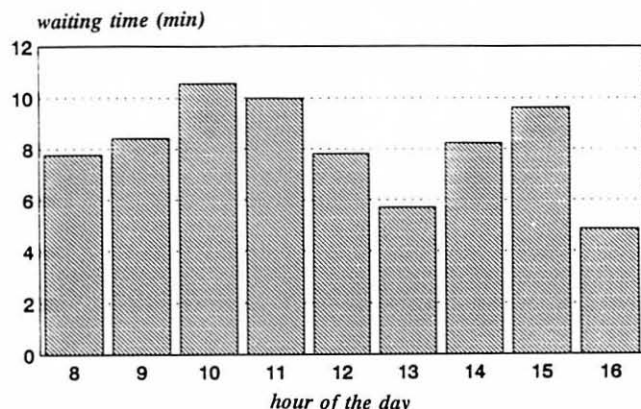


Fig. 2 Example of graphical output (based on 3 months production in a large university hospital)

4. Using clinical data for research and education

Besides departmental management, also educational and research activities can be supported. For this a RIS should contain indexes on the Teaching file and should support multiple indexes to select and retrieve radiological diagnoses.

Radiologists make all kinds of notes and registrations with respect to the diagnostic process and/or to support their research and educational activities. For this purpose they maintain their own card-trays, notebooks, PC files, copies of photo's, etc. These notes are poorly accessible because:

- the notes lack a uniform coding (no coding scheme, different interpretations)
- there is no case based index to the registration, the teaching file can only be organized according to one index at a time
- the amount of time required for retrieval from manual registrations is prohibitive
- there is no direct relationship with other data and reports in RADI / the HIS
- only limited access is possible (authoring radiologist only, one person at a time).

In RADI it is possible to record up to five radiodiagnostic codes for each examination procedure performed. For each procedure up to six additional indexes (characteristics) can be recorded, e.g. teaching file subject, artefact, and radiologist. Also the degree and source of the certainty can be recorded, together with a free text note, if desired. Hospitals can define for themselves which coding scheme to use. In the Netherlands there are several schemes in use, i.a. the ACR coding and an adaptation of the ACR coding scheme by the Dutch Society of Radiologists. However within one hospital RADI supports only the use of one single coding scheme.

By fitting in the registration as a logical step in the diagnostic process, it allows for a fast and easy coding. The registration of the codes can be done by the typist immediately after entering the report; for this is it necessary for the radiologist to speak the appropriate code into the audio-tape. The radiologist can also enter the code himself by means of a separate coding function. Identification of patient and visit can be done by means of reading the barcode ID on the X ray folder. RADI offers support for entering the correct codes by showing for each coding character the next possible code characters according to the coding hierarchy.

Finally the system provides an easy method for (on-line) retrieval of codes and patients. The retrieval of codes can be done patient oriented (e.g. earlier diagnostic findings for this patient) or otherwise. The following selection variables can be used for retrieval: (group of) findings, (group of) examinations, techniques of examinations, visiting date, requester, source of certainty, and characteristics, like teaching file or artefact. This way the radiologist can easily retrieve similar cases which can be of interest both for the diagnostic process itself and for educational or research purposes.

5. Conclusion

To offer optimal support of the activities at the radiology department, a RIS should allow for multiple views on clinical data. By sharing both RIS and HIS clinical data among multiple persons and departments in the hospital, a more efficient and effective support of the clinical process can be given. By using flexible and easy to use retrieval facilities, the operationally recorded clinical data can become available to be used for managerial, educational or research purposes. The philosophy of integration, once-only registration of data which then becomes available for other users throughout the hospital, is essential to achieve this.

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Development and Implementation of an Academic Nuclear Medicine Information Management System and Clinical Imaging Viewing Work Station Based on Personal Computer Technology

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Introduction

The availability of relatively inexpensive, high powered personal computer (PC) technology and readily available database and software development tools has made possible the creation of an all digital, fully computerized nuclear medicine department. Our approach to the design and implementation of an information management system, selection of PC hardware and software as well as selection and utilization of an integrated picture archiving and communication system (PACS) is discussed. The current system has been in place for over one and a half years and consists of multiple networked gamma camera platforms which are integrated with our information management system (IMS) composed of relational controlled-vocabulary patient and study specific databases, report generation tools, editing tools and report retrieval tools running on networked IBM compatible 486 personal computers running the Microsoft Workgroup for Windows 3.11 graphical interface. The PACS operates on an Apple Macintosh platform directly networked into all of our gamma camera computer systems as well as operating as a node of the IBM - PC network.

IMS Database

The IMS database was developed using Superbase 2.0 for Windows (Software Publishing Corp. Santa Clara, Ca). This program was selected on the basis of its many features which include: support of up to 1 billion records with unlimited numbers of fields per record and up to 999 indexes, character field lengths of up to 4000 with external text file support, multilevel password protection, integrated local area networking, support for multiple PC standard image formats and import / export support for DBF and SQL database files. In addition, the program provides an object-oriented, event driven visual programming environment which aided in the development of a graphical form-based interface to the database. With his development tool, the database interface front end was designed such that information entry and vocabulary could be completely controlled through point and click selection of lookup tables and menus. By eliminating purely free text entry in our database interface design, exact information is consistently recorded into the database which has the advantage of making future database queries maximally efficient with no loss of relevant records due to syntactical differences or the use of synonymous terms or lexical variants (Figure 1a & 1b).

Figure 1a. Menu screen of the IMS study database.

Figure 1b. Database study entry screen demonstrating an example of one of the many pop-up lookup tables from which entries are made.

Superbase - D:\SD4\WNUC MED Indexed on LastName

File Edit View Data Utilities Options Program Help

San Francisco General Hospital Nuclear Medicine Patient Report Database

Abdoun	Elsada	00198724	9403-200	(01.02) Myocardial Perfusion Exercise Tc-99m	3/21/1994	Complete
Adkular	Salen	00222507	9309-122	(01.02) Myocardial Perfusion Exercise Tc-99m	9/27/1993	Complete
Adi-Ohanem	Watise	00066230	9404-112	(05.03) Lung Ventilation Xenon-133	4/20/1993	Complete
Adig	Kickup	00736516	9302-27	(03.04) Bone WB	9/11/1993	Complete
Adrahime	Winche	01144151	9311-120	(01.02) Myocardial Perfusion Exercise Tc-99m	11/30/1993	Complete
Adrahim	Mosammed	01186251	9308-105	(01.02) Myocardial Perfusion Exercise Tc-99m	8/15/1993	Complete
Adi	Victors	00303503	9210-51	(08.03) WB-Tc-99m-MIBI	10/15/1992	Complete
Agueda	Rita	01153610	9304-122	(03.02) Bone Flow/Scan WB+Statisc	4/21/1993	Complete
Akers	Edith	01022727	9402-148	(07.08) Thyroid Uptake T-123	2/28/1994	Complete
ACKERSON	MARGOLD	00371430	9304-38	(01.02) Myocardial Perfusion Exercise Tc-99m	4/09/1993	Complete

Access to Editing Allowed Use the '?' to find a Patient

Figure 1c. Database menu screen demonstrating the user report retrieval interface which includes listing of the patient names, identification numbers, study date, type of study and the status of the report (complete or not complete).

The IMS database is utilized in nearly all aspects of information flow in our department. Front desk staff access the IMS database to schedule patient procedures and log-in patients upon their arrival. Each patient study is given a unique identification number which is then used for tracking and linking to all subsequent related information. Technologists use the database to produce patient procedure specific worksheets which are used to record study and quality assurance information. They also have the ability to retrieve old patient study records for information which may include special procedures and technical variations required during the patient's previous visits (Figure 1c). Staff generate study reports by selecting the patient study from the IMS database and interacting with a template producing program which automatically generates a report in a standard (off the shelf) full word-processing program (Microsoft Word for Windows 6.0) which is then ready for additional edits, spell checking and merging representative images. If the report is not directly entered by the staff, the same tools sets are used by the transcriptionists to generate reports. With these tools, preliminary clinical reports generated by residents can be generated in as little as 2 to 5 minutes and immediately available to attending staff for review and finalization. Using dynamic data exchange (DDE), a feature of many Microsoft Windows applications, programmable background communications between the database, template generating program and word processing program are possible which then allows sharing of information between applications, report text formatting and storage to be completely automated. Using several application programs each specifically designed for different tasks with DDE linking offers the advantage of seamless interaction and has been key in insuring consistency in sequential file naming conventions, network repository location and security of patient sensitive data. The

IMS database additionally allows the staff to easily access current and previous study results, record follow-up patient information and correlative study results, generate reports and statistical information for research, resource utilization and quality assurance.

Hardware and Network

The major advantage in the use of PC technology has been the vast and growing selection of high performance desktop computers and peripherals as well as the significant purchase savings driven by a large scale marketplace. The already wide and ever increasing distribution of these computers, corresponding development tools and software has led to the accelerated discovery and improvement in the technology.

Since both Macintosh PCs and IBM compatible personal computers running Microsoft Windows software offer comparable easy to use graphical user interfaces and have the ability to be networked using several protocols simultaneously, choosing a single PC platform was unnecessary. Selection was made on the basis of optimal performance and tools available for the particular platform designed for the desired specific task as well as for overall price. In this manner, IBM compatible 486 PCs running Microsoft's Windows for Workgroups 3.11 were selected as the platform for the database, word processing program, study report repository and overall office management tools. The PC network is configured in distributed ethernet local area network as outlined in Figure 2.

Selection of a centralized image viewing workstation was guided by our needs to view and archive studies acquired on gamma cameras from multiple vendors including General Electric (GE), Trionix and Siemens Icon as well as our desire to contain costs. After evaluating several vendors, we found the DeltaManager image management software (Medimage Ann Arbor, MI) which runs on the Apple Macintosh to be the most appropriate choice. Although the post acquisition processing of this software is limited, we found image display capabilities to be excellent. Single photon emission computed tomography (SPECT) myocardial perfusion studies make up a significant portion of our workload. Efficient display of these types of studies therefore played a major role in our decision to use the DeltaManager. We were initially and continue to be impressed with the speed and flexibility of the program's tomographic display. Unlike many other systems which create separate files for transaxial, sagittal and coronal datasets, the DeltaManager system dynamically generates coronal and sagittal slices from the transaxial slices. This technique uses less overall computer memory and enables very fast image manipulation such as three slice triangulation and combination of datasets for slice to slice comparison (Figure 3).

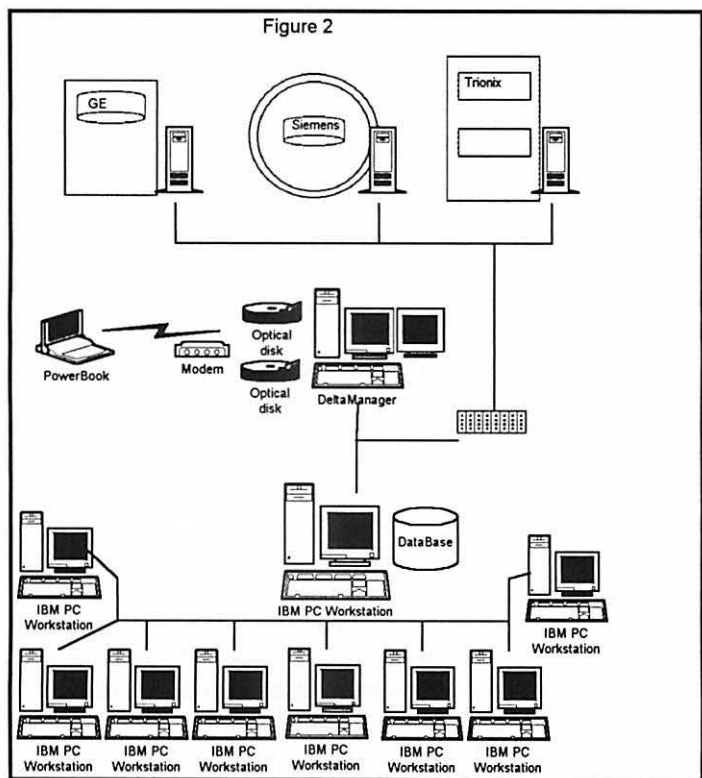


Figure 2. Network diagram demonstrating the configuration of the gamma cameras, central viewing workstation and PC LAN.

In our department, all clinical images are transferred for initial and final analysis to the DeltaManager workstation after acquisition and processing on the gamma camera computer systems. Networking to the gamma cameras is accomplished via multiple simultaneously running network protocols. These include Macintosh Open Systems Interconnection (MacOSI) for GE networking, File Transfer Protocol (FTP) via TCP/IP for the Trionix and file sharing via Apple File Protocol (AFP) for the Siemens Icon. The overall speed of file transfer is fairly rapid with 2 megabytes of data transferring in approximately 1 to 2 minutes. The workstation accesses two daisy chained small computer serial interface (SCSI) 1 Gigabyte removable optical disk storage devices, each which has the ability to store approximately 4 months of our department's imaging studies or over 3000 individual images per disk. Studies can be recalled directly from the optical disks without the need to transfer the datasets back to the local hard drive on the Deltamanager. Recall of previous studies for analysis or comparison is therefore very rapid with disk access speeds of approximately 30 to 50 msec. Patient study location pointers to the optical disk library are maintained in the IMS database.

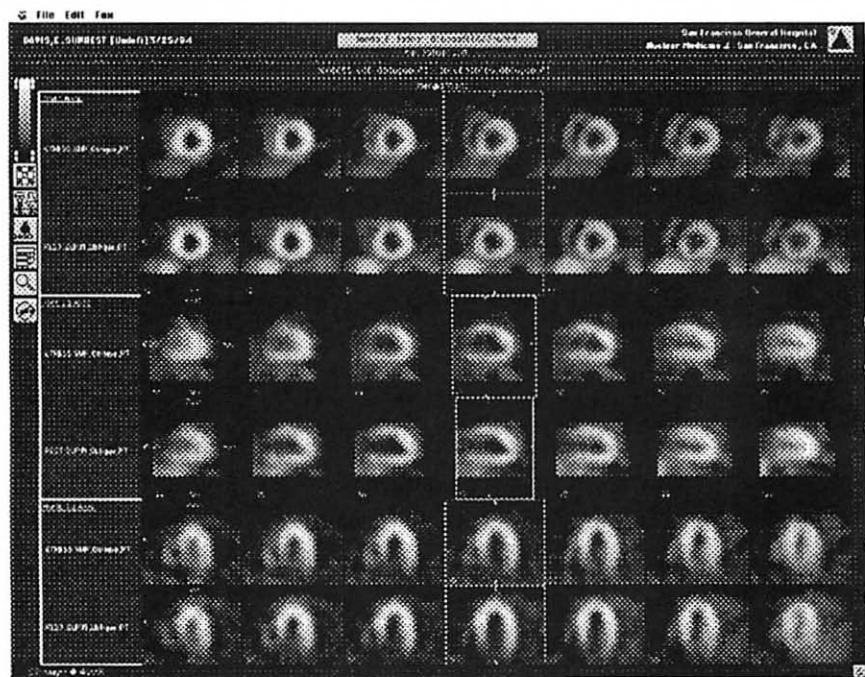


Figure 3. Window from the DeltaManager displaying a post stress and resting myocardial perfusion study in a three view (short axis, vertical long axis and horizontal long axis) comparison.

The Delatamanager image viewing workstation also provides features which allows for the generation of QuickTime movies for teaching file purposes as well as clipping of selected representative images which can then be saved and transferred to the IBM - PC network for inclusion in the clinical reports. Another important feature of the Delatamanager system is remote access accomplished through the use of portable Macintosh PowerBook color computers equipped with high speed modems, Apple Remote Access (ARA) software for remote communication and drive redirection as well as fully functional image viewing software.

The development and implementation of the information management and centralized clinical imaging viewing and archival systems based on personal computer technology has been cost effective and well-received by both staff physicians and technologists. By allowing rapid analysis of imaging studies without the need to wait for film development as well as improving generation and access to study reports, the overall impact of the computerized system has been to substantially improve timeliness of study analysis and enhance report generation speed and format. It has also served to facilitate the improved management of patient follow-up, quality assurance and resource utilization data in an effort to strengthen management control for the containment of health care costs in an academic nuclear medicine department.

Radiotherapy Information Management System

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I. INTRODUCTION

The complexity of modern radiotherapy practice, including clinical, academic, and financial operations, as well as data transfer within a department and with the outside world including, for example, private, federal and scientific entities (referring physicians, third party payors, Medicare, RTOG, etc.) requires the efficient management of large amounts of information. Without adequate automation, it is difficult to accomplish this task rapidly and accurately. We report here on the design and implementation of a computer network system conceived expressly for this purpose.

The system is a PC based Ethernet local area network that uses only commercially available hardware and software such as DOS and Novell operating systems. The network is modular and its composition can easily be modified to accommodate the changing needs of the department. The network permits immediate integration of different computers, as well as unification of software resources. In addition to standard word processing, database, spreadsheet, and optical scanning application programs, radiotherapy-specific software for information management and tumor registry are also vital components of the system. The network integrates the bulk of radiotherapy hardware, including three computer-controlled accelerators, two computer-controlled simulators, and a treatment planning facility. The network also incorporates the majority of departmental operations in the clinical, research and administrative areas.

II. METHODS

The system is built around two IBM 95XP 486 / 50 MHz file servers and a 56 GByte optical/magnetic storage facility. The network includes eighty 286 - 486 / 16 - 33 MHz personal computers (PCs) configured as workstations, print, FAX, and transcription servers, two optical scanning stations, and a multimedia access/educational center. A schematic diagram of the system is shown in Figure 1.

The core of the radiotherapy information management system consists of three commercially available software products used in concert to form a complete electronic patient chart and radiotherapy information analysis structure. A brief overview of these three program packages is provided herein:

The IMPAC ACCESS patient/treatment data management software is a primary component of the information management system. It is comprised of a suite of modules that facilitate the following aspects of departmental operations:

- patient registration
- patient consult, treatment and follow-up visit scheduling
- simulator/accelerator scheduling for regular periodic quality assurance testing and preventive maintenance
- computer acquisition and storage of simulation fields
- dosimetric parameter input, including treatment field monitor units and secondary dose point ratios
- automated accelerator set-up and record-and-verify
- automatic charge capture
- complete billing services
- statistical analysis of patient demographic and treatment information for departmental planning purposes
- management / informational reporting tools for financial and accounting purposes
- staff quality control checklist

The IMS 2020 document archiving/retrieval system produced by Lanier Worldwide Corporation is the second important constituent of the system, and is used for digitization and storage of all paper documentation received from outside, as well as that generated within our department. The 56 Gbyte optical/magnetic storage

facility used in conjunction with this software consists of a 50 platter CD jukebox and six separate on-line optical drives. In addition to patient hardcopy information storage, this system is used as a computer library to provide rapid, widespread access to manuals, technical articles and other scanned paper documentation of interest to departmental staff.

Finally, a computerized tumor registry based upon ONCOLOG software, and tailored to radiotherapy-specific requirements is also available on the network. This program is used to record patient disease staging, treatment, complication and response parameters to track patient disease-free and actuarial survivals. All patients have this information entered into the computer, with additional data input depending upon the patient's medical history, disease site and staging and participation in specific RTOG and in-house clinical study research protocols. A useful consequent application of this database is, for example, the generation of data for Morbidity and Mortality reports, or tracking any number of quality assurance and improvement parameters required by the Joint Commission on Accreditation of Hospital Operations (JCAHO).

As in any modern computer-equipped medical facility, our department also utilizes software to handle wordprocessing, database design, spreadsheet applications, graphics production, computer-aided design, electronic mail and global communication links via the Internet.

III. DISCUSSION

Staff input, acceptance, co-operation and adequate initial training are essential to the successful implementation of a radiotherapy information management system and subsequent transition from a conventional paper-chart based practice to completely computer-based electronic information management.

Once staff had become accustomed to and efficient at using the system, considerable benefits to patients and the department as a whole were realized, in terms of both convenience and time-saving issues. For example, patient information may be accessed at any computer terminal within the department, completely eliminating the incidence of unavailable charts. The automatic accelerator set-up and record-and-verify capabilities of the IMPAC ACCESS software package allow our

technologists to spend more of their time per treatment session ensuring accurate patient positioning, and interacting more with patients, which helps reduce patient apprehension, prevents treatment delivery errors and eliminates much of the time otherwise expended record-keeping.

As with any composite system, seamless integration of all components can present difficulties. Different user interfaces coupled with the necessity of having to regularly enter and then exit programs to access different applications can result in barriers to efficient system use. Additionally, the integration of older hardware can also result in system performance limitations. However, with appropriate matching of hardware resources and individual personnel functions, these problems can be minimized.

The network described herein has been in operation for two years and has proven sufficient for departmental needs. The department sees approximately 1,000 new patients per year and encompasses a space roughly 40,000 square feet in area.

IV. CONCLUSIONS

A PC based radiotherapy information management system is cost effective. In comparison with established standards, it excels in both rapidity and accuracy of data generation, processing, storage, and retrieval operations.

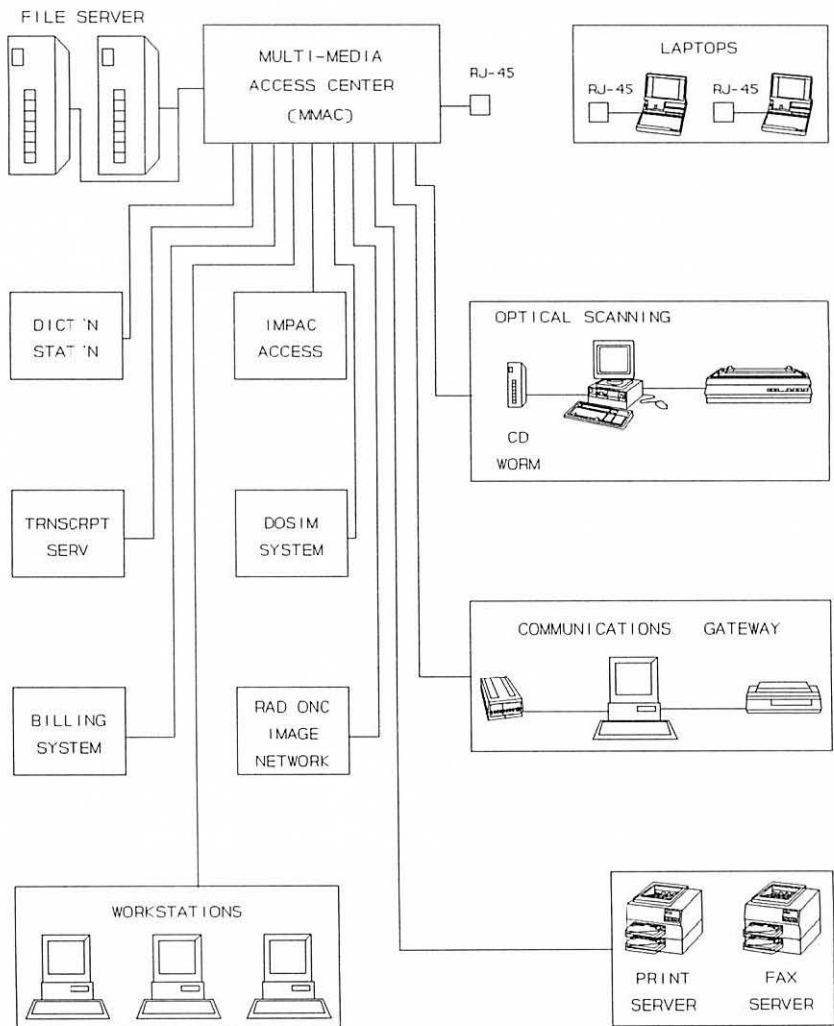


Figure 1. Schematic representation displaying constituent components and links that form the Radiotherapy Information Management System.

A Modular Information System to Support Clinical and Research Interests in a Breast Imaging Center

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Introduction

More than any other Radiology specialty, mammography has attracted national attention and with it has come increasing scrutiny and regulation. The challenge of providing high quality healthcare while adhering to regulations makes mammography ideally suited to automation. Computerization of the work flow in a breast imaging center makes it possible to handle large volumes of patients efficiently, evaluate outcomes, document adherence to federal, state and JCAHO regulations and accommodate research interests.

Design Objectives

The overall goal in computerizing the entire breast imaging facility was to increase the accuracy and completeness of information from initial scheduling to final reporting and patient follow-up. Routine operations in a breast imaging center have become so complex that it is nearly impossible to maximize patient throughput, maintain the accuracy of all data collected, and guarantee compliance with all regulations without using a computer in some capacity. In designing this information system, we tried to automate as much of the operation of the breast imaging center as possible while striving to provide maximum flexibility.

Several key objectives influenced the system design:

- Direct data entry by all staff members. – We considered direct data entry by the users to be an important method of reducing transcription errors and ensuring data entry. To reduce dependence on paper in management operations we replaced most paper forms with an equivalent computerized operation. For the system to work well, we believed it was necessary to have the data entered by all staff members in real time. Accordingly, we structured the system to allow easy input of all data.
- System prompts for additional sequential actions. - We decided that the system should be responsible for helping users adhere to certain rules and procedures. The program does this by either modifying choices (enabling or disabling options) or notifying the appropriate people of actions to be

performed (e.g., rescheduling for additional exams or film requests). There are many situations where certain conditions should trigger a response or action. In a non-computerized environment, the response occurs only if the people involved recognize the conditions and they are able to respond before they forget or become distracted. We also decided that the system would not force any optional or required action if the user did not desire it. In some cases, however, the system requires actions before other functions become available, so failure to take an appropriate action could result in an inability to perform another action later. This inability to access a certain function forces staff members to go back and correct or amend the previously omitted steps if they want the subsequent action to occur. Since it is often a combination of actions that leads to a desired result, this design compels staff members to enter data and perform all actions at the appropriate times. The use of work lists throughout the program ensures that individual tasks do not get overlooked.

- Flexibility in configuration. – The system needed to be broadly configurable to perform correctly in different sites and to respond to changes in clinical practice or regulations without requiring additional programming. We took care to ensure that system flexibility did not compromise accurate capture of important or essential data. This allows the system to be as comprehensive as possible without being excessively restrictive.
- Standard terminology. – We designed the reporting module to follow the lexicon recommended by the Breast Imaging Reporting and Data System (BIRADS) of the ACR for as many cases as applicable.¹ Since some cases can not be interpreted using the BIRADS lexicon, the program allows input as free text when necessary.
- Comprehensive reporting capability. – Although automation is most important for screening mammography, our objective was to design the system to encompass all activities and all imaging procedures in a breast imaging center.

System Overview

The mammography system was developed to mimic and replace most of the manual operations that are essential in a busy breast imaging facility. The system records information necessary for regulatory agencies and research. The application and database manage interrelationships of the data whenever possible. The system has a client/server architecture and uses a relational database engine (Sybase) as the database server. All data are stored in a single database accessible from a variety of platforms and physical locations over an Ethernet network. A detailed description of features is beyond the scope of this paper.

We developed the system as a number of interacting modules. Each module handles a group of related operations in the department. There are 5 general modules:

1. Scheduling
2. Patient Tracking
3. Recording Medical History
4. Exam Interpretation
5. Statistical Reporting

In addition there are several additional features supported separately that were necessary or desired for efficient operations:

6. Immediate transcription and generation of patient reports or screening letters (printing occurs after interpretation approval)
7. Reminder notices (based on information from scheduling)
8. Outside film tracking (tracking requests for outside films and verifying their return)
9. Management reports for general operational queries.

The scheduling module is similar in many respects to scheduling programs in any Radiology Information System. One of the major advantages of this module is the graphical user interface that makes it easy to picture the schedule for any day and easy to schedule, reschedule or move any appointment (Figure 1). The program creates a "scheduling worklist" for exams that need to be scheduled or rescheduled. When the radiologist recommends a follow-up appointment, for example, it is added automatically to this work list.

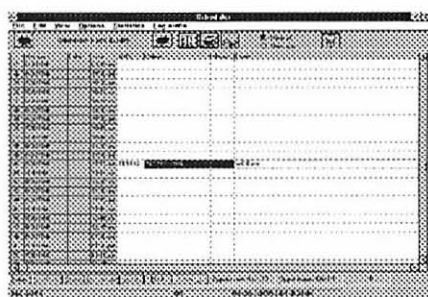


Figure 1: Scheduling Screen

As appointments are scheduled, the program deletes patient names from the work list. An offshoot of scheduling is the ability to send either reminder notices to scheduled patients or notices requesting them to call to schedule follow-up exams.

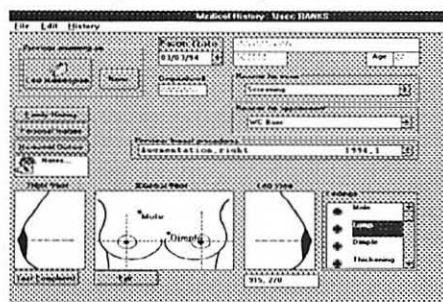


Figure 2: Medical History Entry Screen

Patient tracking monitors patient flow through the breast imaging section. As patients arrive in the department, the receptionist marks them in the system as having arrived. Similar features allow the section personnel to record that the exam is in progress or completed. In this module, the program assigns a requisition number to the

clinician and letters to the patients.

Since the system requires immediate data input by all staff members, statistical reporting is always available and current. The data are stored in a relational database, making it available for review using a number of reporting tools. The system has a number of standard reports to handle the presently identified reporting needs. Additional reports can be customized to present the data differently. Computerized forms for entering pathology results are provided. Direct links to pathology databases and/or tumor registries are possible. The addition of pathology results to the database makes it possible to assess radiologists' accuracy and other performance parameters.

Benefits of the System

This information system provides benefits related to several functions of a breast imaging center.

Clinical. The system eliminates redundant recording of demographic and medical history information. Once the information is entered it is available to all users at all times. Users can update or correct the information annually or as needed, but they need enter only changes or new data.

Another benefit to patients and staff is that the entered information should be more accurate than in systems that rely on subsequent transcription. Direct input of all information, including exam interpretations, by the person responsible for the accuracy of the data eliminates transcription errors and provides immediate availability of the data to others.

Consistency in terminology used for history-taking and exam interpretation is another benefit. Only certain choices are available to the technologists during verification and updating of the history. Standardized marking of findings on an anatomic diagram is another feature of the system. The variability of radiologists' interpretations has been a significant problem for many referring clinicians. Use of the BIRADS lexicon should result in more consistent reporting of findings and conclusions by leading the radiologist through the interpretation process in an orderly, stepwise fashion. Referring to mammography, it has recently been stated that "standardized terminology contributes to an orderly thought process leading to logical recommendations."²

Final printed reports for referring physicians are available immediately as well as form letters for the patients describing the results of their mammograms in layman's terms.

Administrative. One of the principal benefits of the system is the capture and organization of data to comply with state, federal, and JCAHO regulations.

Direct entry of results into a computer system provides documentation of the effort expended and the results obtained for each patient encounter. Overall, direct entry of data by the personnel responsible should result in an efficiency in operations. When the reporting module is used to enter all interpretation results, the data collected can be pooled with other regional and national data to monitor local, regional and national trends and outcomes in a consistent manner.

Educational. The standardized format and terminology (lexicon) provide an effective teaching tool for radiology residents and others learning mammographic interpretation.

Research. The availability of accurate data in an accessible, long-term database facilitates a variety of research projects. For example, it makes possible the incorporation and investigation of diagnostic aids such as neural networks that predict the probability of malignancy for a given finding. Furthermore, research on outcomes or practice guidelines requires data collected in a standardized fashion over many years.

Disadvantages

Initial disadvantages of developing this system were the costs of hardware and programming time. There was also an unmeasurable cost in lost professional and staff time from individuals who were unfamiliar with using computers. The amount of ongoing operational support needed from computer professionals is not known.

A disadvantage from the radiologists' perspective is the necessity to look at the screen and away from the films to enter the interpretation. This could be obviated in the future by voice-activated commands.

Conclusion

This comprehensive information system for a breast imaging facility automates all manual data recording and administrative functions, improves efficiency, accuracy and completeness, and accrues benefits to patients, support staff, referring physicians, radiologist and administrators.

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¹Kopans D. B., D'Orsi C. J., Adler D. D., et al. *American College of Radiology breast imaging reporting and data system ACR*, 1993

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Automated Computerized Equipment Assessment Program

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As the information age unfolds, North Americans increasingly are coming under pressure to do what they are presently doing in less time. In other words, their time must be spent more productively.

The ever-increasing time required to analyze complex equipment tenders multiplies the demands on managers in areas, such as Purchasing and Diagnostic Imaging. While the use of tendering for equipment purchases is common throughout North America, a complete computer program to facilitate this process previously has not been available.

ANDREA, designed to run on MS-DOS compatible microcomputers, is a sophisticated computerized program for tendering simple or complex equipment. Developed by RAYDAC Enterprises Ltd., Spruce Grove, Alberta, ANDREA was site tested at Misericordia Hospital, a member of the Caritas Health Group, and the Royal Alexandra Hospital, both in Edmonton, Alberta, Canada.

The ANDREA program facilitates development of common bidding instructions, options/accessories and technical specifications for equipment. This computerized method allows all vendors to be treated equal during the technical and financial evaluations of tender responses.

Originally designed for use in tendering Diagnostic Imaging equipment, ANDREA has applications in other industries. When a client wants to evaluate equipment specifications, the software encompasses all phases of equipment acquisition assessment. ANDREA provides an effective method for comparing vendor responses by assigning relative weights to specifications. Vendor responses are automatically displayed in tables that include cost summaries, weight averaging,

options and accessories. The resulting cost analysis reflects true value to the client.

The software allows its users to create technical specifications with weighted value of importance and coding methods that allow the client to identify if the vendors meet, exceed or are non-compliant in their responses.

In addition to being unique and cost effective, ANDREA is user friendly. Proficiency with the system is usually achieved within a matter of hours. Vendors do not need to purchase any special software in order to respond to tenders. All necessary software is provided on the vendor diskettes created by the program. The overall process is outlined in Figure I.

The client identifies and creates the list of vendors who will be invited to bid on the proposed equipment. As part of the client's input, tender specifications are created including bidder's instructions, technical specifications together with options and accessories specifications. On completion of the specifications, a vendor diskette is created and sent along with a paper copy of the tender to the vendors for response.

ANDREA is then loaded by the vendors onto their personal computers. Some vendors have become so familiar with this software that they prefer to respond directly onto the diskette supplied without using the paper documentation. (Some companies choose to use the paper tender documents to fill in the responses and then transfer them to the diskette when completed.) The vendor may also print a paper copy of responses for their permanent records.

On completion the vendor returns the tender to the client, in this case, Diagnostic Imaging Service, on the date, time and location specified. On receipt of tender responses from vendors, the client reviews and codes each response as, "meets/exceeds; needs discussion; or does not meet specifications." This initial step should not exceed more than 30 to 60 minutes per vendor. When the initial coding is completed, by selecting reports, the evaluator can generate a number of comparative analyses to use and discuss with the client equipment team or committee.

Specifications identified as needing clarification with the client equipment team or vendors can be identified by a

numerical code assigned to identify further discussion, and verified for final coding with the vendors during a vendor presentation or site visit.

SUMMARY

ANDREA allows the vendors to be treated equal during the technical and financial evaluation of tender responses while documenting their contractual obligations in a permanent document. In addition, the program will create an electronic or paper tender document customized to the client's own specifications.

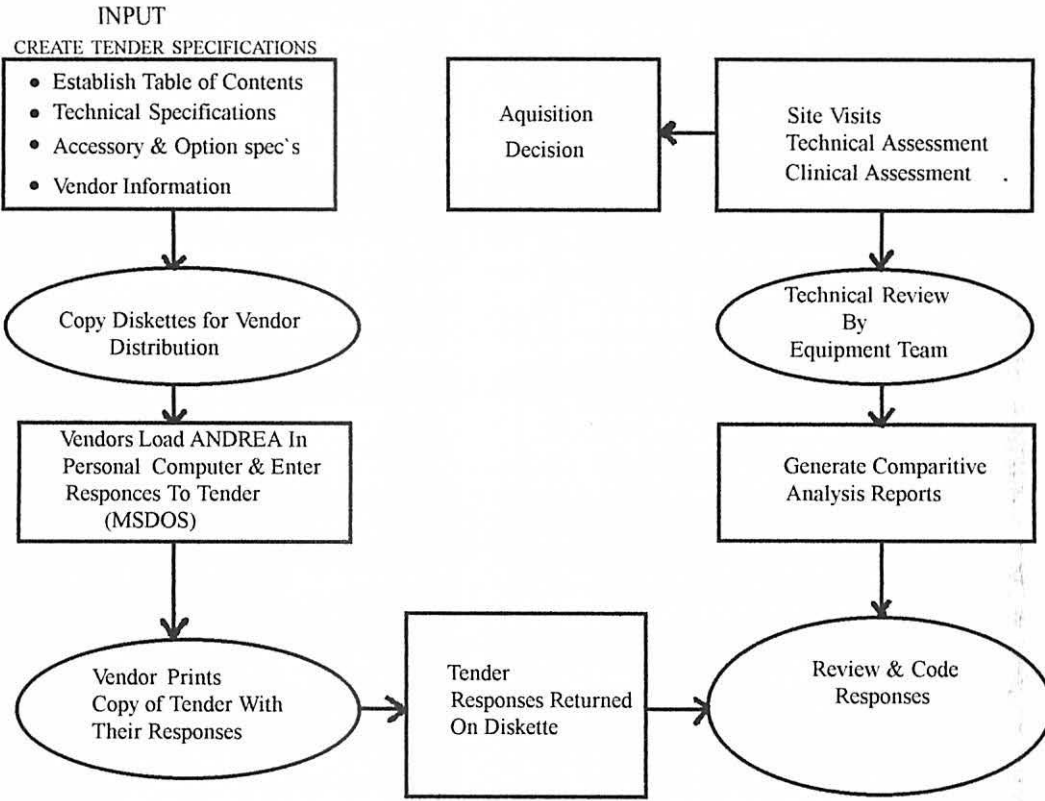
To date, over 10 million dollars have been tendered using this software, including major equipment in Computed Tomography, Ultrasound, film processors, laser cameras, Nuclear Medicine Gamma Cameras and Radiology equipment.

ANDREA runs on a personal computer (MSDOS) and is a program onto its own. This program does not require other software to be purchased by the vendor, and offers the following to its users:

- significant time reduction for managers when evaluating and purchasing equipment;
- linkage with vendors by diskette or paper documents, or both;
- generation of a comprehensive report package, including result tables comparing multiple companies at one time, cost comparisons, technical weighting of specifications and degree of vendor compliance;
- the ability to edit, merge, clone and renumber all or any part of an existing tender, and
- generation of a full analysis spreadsheet of four bids before the end of one working day.

Generally, computerized software like ANDREA can save professional managers and directors substantial man hours which can be directed to other need challenges.

ANDREA SOFTWARE
VERSION 2.1
PROCESS



This Software has been reported by others to cut 30% in production time and at least 50% in Tender Analysis time.

FIGURE I

SESSION 15

Public Health

Chair: Melvyn Greberman

Computer-Assisted Radiology: Research Support at the Diagnostic Imaging Research Branch, National Cancer Institute

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Diagnostic Imaging Research Branch (DIRB) is the leading extramural, research-sponsoring organizational unit in imaging science at the National Cancer Institute (NCI). As an extramural part of NCI, DIRB has two major responsibilities: 1) administration of investigator-initiated grants; and 2) development of national policy in imaging science.

In Fiscal Year (FY) 1993, computer-assisted radiology (CAR) research support comprised about \$16.5 Mln, or 30.6% of the annual DIRB budget (See Fig. 1). Currently, DIRB annual CAR support is only slightly smaller compared to Magnetic Resonance Imaging and Spectroscopy, the largest area of research expenditures. Among the CAR-supported research fields, the largest portion of funds is allocated to image processing, computer-aided diagnosis and three-dimensional imaging at 37.19%, closely followed by PACS-related technologies (workstation and other hardware design, teleradiology, etc.) at 28.3% and other digital imaging technologies at 23.57%. On the other hand, knowledge-based system development comprises only 6.6% and cognitive perception research 4.3% of the DIRB annual CAR-related expenditures.

As policy makers, DIRB staff members have the responsibility to develop new national and international research programs in imaging science. Over the last several years, DIRB staff proposed and supported several CAR initiatives: 1) National Digital Mammography Development Group (1,2); 2) Quantitation of Tumor Response to Treatment: a Three-Dimensional Approach (1,3); 3) Radiologic Diagnostic Oncology Group V: Stereotactic Tissue Diagnosis in Non-Palpable Breast Cancer (4); 4) Federal Technology Transfer Program in Digital Mammography (5,6); and 5) Medical Imaging Databases (7,8). While the first two DIRB programs were described at SCAR'92 (1), this paper will focus on the recent NCI research initiatives proposed and funded since that time, their background, rationale, goals and scope.

1) Radiologic Diagnostic Oncology Group V: Stereotactic Tissue Diagnosis in Non-Palpable Breast Cancer.

Background

The objective of the NCI initiative entitled "Radiologic Diagnostic Oncology Group V: Stereotactic Tissue Diagnosis in Non-Palpable Breast Cancer" is to facilitate development of an optimal clinical algorithm for characterization of small subclinical breast cancers through a centrally coordinated multi-center cooperative clinical study.

The Radiologic Diagnostic Oncology Group (RDOG) was formed in September, 1987, in response to a DIRB/NCI Request for Applications (RFA). The RDOG objective is timely evaluation of current and emerging imaging modalities in the management of patients with cancer. The development of multi-institutional clinical trial groups allows for rapid patient accrual within a short period of time. This in turn assures rapid evaluation and optimization of imaging techniques for diagnosis, staging and serial monitoring of cancer, with early dissemination to the public of proven new methods.

Since the time of its establishment, RDOG clinical research has been important for the development of optimal imaging algorithms for prostate and lung cancer (RDOG I), pancreatic and colon cancer (RDOG II), musculoskeletal and head and neck cancer (RDOG III) and ovarian and pediatric solid tumor imaging (RDOG IV). Seven protocols are currently underway in twenty three academic centers in this country.

RDOG has had significant impact on clinical research in Radiology. This is the first time that multi-institutional clinical trials in diagnostic imaging have been conducted in a centrally coordinated fashion with strict quality control and analysis of cost-effectiveness. Ultimately, RDOG study findings will be useful for design of therapeutic protocols, in formulating clinical and reimbursement policy.

The specific focus of RDOG V is to study imaging-guided stereotactic breast lesion biopsy as a minimally invasive alternative to an open surgical biopsy. This RFA is based on the recommendations of the NCI workshop organized by the Diagnostic Imaging Research Branch of the Division of Cancer Treatment in collaboration with the Early Detection Branch of the Division of Cancer Prevention and Control.

The majority of patients (about 80%) undergoing open surgical biopsy of the breast lesions do not have cancer. Recently, imaging-guided stereotactic breast biopsy has emerged as a minimally invasive novel tool with the potential to replace open surgical biopsy in a significant

fraction of patients. There are two potential advantages of stereotactic breast biopsies as compared to surgery: 1) minimization of tissue damage (and thus improvement in cosmetic results); and 2) cost effectiveness. In addition, recent reports indicate that stereotactic technique, which allows for precise, quantitative, pinpoint localization of breast lesions, improves diagnostic yield of conventional free-handed approaches to imaging-guided biopsy of breast lesions; indeed, stereotactic methodology may decrease the insufficient sample rate when fine needle biopsy is performed (Schmidt R., University of Chicago, Presented at the NCI Workshop, September 5, 1991).

Two approaches to imaging-guided stereotactic breast tissue diagnosis are employed: 1) Stereotactic Fine Needle Aspiration (SFNA); and 2) Stereotactic Core Needle Biopsy (SCNB). SFNA produces aspiration cytology, while SCNB produces tissue samples comparable to open surgery. The sensitivity of SFNA as compared to open surgery ranges from 79 to 100% (depending on the center), while the insufficient sample rate ranges from 0 to 25% (Schmidt R., University of Chicago, Presented at the NCI Workshop, September 5, 1991). The sensitivity for SCNB, on the other hand, was reported at 95% compared to open surgical biopsy-- with no insufficient samples (Parker et al. Radiology 1991; 180:403-407; Parker et al. Radiology 1990; 176:741-747). SCNB and in particular SFNA are less traumatic than open surgery, and the cost of stereotactic tissue diagnosis is about 28% of that for surgical procedures.

In summary, these preliminary clinical data indicate patient benefit and cost-effectiveness of imaging-guided stereotactic breast biopsy as compared to open surgical biopsy. However, indications for stereotactic (SFNA vs SCNB) as compared to open surgical biopsy have not been defined, and a number of questions remain to be addressed (e.g. false negative rate--missed lesions, the quality of samples, etc.).

Research Goals

The goal of this RFA is to stimulate multi-center evaluation of imaging-guided stereotactic breast lesion biopsy and its impact on patient management and cost-effectiveness as compared to open surgical biopsy. Major clinical questions can be answered by such a study: 1) what specific stereotactic technique is most appropriate?; 2) can stereotactic breast biopsy replace open surgery? and if yes, in what specific clinical situations? in what percentage of patients?; 3) what gain in patient management and healthcare costs can be achieved?. In order to address these questions, a centrally-coordinated, cooperative, multi-institutional study, with consensus-based experimental design development and data analysis was funded by NCI.

2) Medical Imaging Databases

Background

The purpose of the NCI initiative entitled "Medical Imaging Databases" is to facilitate research that will address new medical imaging database designs that focus on non-textual paradigms. The goal of medical imaging databases is to provide a means for organizing a large mass of heterogeneous, changing, pictorial, and symbolic data into a structured environment that can be synthesized, classified, and presented in an organized efficient manner to facilitate optimal decision making in a health care environment. A properly organized imaging database can compensate for human memory limitations and provide an environment for improved patient care, research, and education. Development of an effective and useful medical imaging database must take place in an interdisciplinary environment, using the medical knowledge from radiologists, radiation and medical oncologists, neurologists and other specialties in collaboration with the database research community and the imaging expertise of the computer and Picture Archiving and Communications System (PACS) sciences.

Today, medical imaging database management and searches are largely performed by skilled human investigators. Although considerable progress has been achieved in recent years in the development of new strategies for rapid and efficient textual retrievals from text databases, very little effort has gone into the development of techniques for non-textual searches. Similarly, since medical images are poorly incorporated into the overall collection of data on cancer patients, there is very little attempt to cohesively gather information from images of different patients for correlation with other critical parameters of their disease. The wealth of information that is potentially accessible, but not available through any currently available technology, would contribute to new clinical knowledge about disease progression, prognostic indicators for outcome assessment in patients scheduled for treatment, and the ability to assess outcome in patients who have undergone treatment.

Research Goals

Although much research has already been done in the development of "next generation databases," more research is needed to address the complex issues of developing the tools for medical imaging databases in a clinical environment. The research goals of this Program Announcement include the following:

1. Development of a descriptive language for medical images that describes image features that define the oncologic content of images

and develops a standardized vocabulary for the geometric description of the images;

2. Development and implementation of advanced query languages that use pictorial and symbolic-based object-oriented data modeling to support complex non-textual queries;

3. Development of new database models that incorporate the following features:

- a. index an imaging database using image features;
- b. support spatial relations for queries that can detect change, such as by shape and size, but are robust enough to adjust for deformations;
- c. develop object-oriented solutions that can handle levels of uncertainty in identifying objects with fuzzy boundaries;
- d. support temporal relations that reflect both the history of the patient, as is currently best known, as well as what was in the database at any given point in time;
- e. allow for the development of ad hoc and customized schema that evolve as the user gathers new data and knowledge by navigating through or perusing the database;
- f. solve integrity problems, such as resolving a situation when two databases contain contradictory information;
- g. carry out search and analysis processes that are both accurate and timely and allow for the interaction of a human investigator.

5. Development of tools that allow for the cohesive unification of data and information from hospital information systems, radiological information systems, image archives and imaging machines into one system for incorporation into the electronic medical record for incorporation into the electronic medical record.

Research and implementations of database systems must proceed in interdisciplinary environments that successfully combine the expertise and knowledge from the medical community with that of the database and computer science disciplines.

This on-going Program Announcement is currently active.

3) Federal Technology Transfer Program in Digital Mammography

Background

The purpose of the NCI initiative "Federal Technology Transfer Program in Digital Mammography" is to facilitate development of digital mammography and related technologies, including but not limited to the following areas: 1) digital detectors and display systems; 2) novel algorithms for image processing and computer-aided diagnosis; and 3) novel high performance, low cost networks for telemammography. This program was jointly developed with and would be co-sponsored by the National Aeronautics and Space Agency (NASA).

Digital mammography is one of the most promising novel technologies for early detection of breast cancer. Digital images offer several potential advantages in image quality compared to conventional film-based systems, including improved image contrast and resolution at a lower radiation dose, and offer the additional benefits of computerized image enhancement and image analysis, computerized image archiving, and the possibility of image transmission for analysis at a distant site (teleradiology), which could bring world-class expertise to community hospitals. A Program Announcement entitled "National Digital Mammography Development Group" (PA-92-57, NIH Guide for Grants and Contracts, Volume 21, March 27, 1992) was approved by the Division of Cancer Treatment's Board of Scientific Counselors and has resulted in the funding by the NCI of a multi-disciplinary, international group consisting of four academic centers and two industrial components aimed at developing this technology. We are convinced that the development of all aspects of this technology will result in better quality mammographic images, more reliable interpretation, and greater dissemination of state-of-the-art screening to a greater proportion of the U.S. population of women at risk, with a resultant significant probability of saving lives. As the recent data indicate, digital mammography may be of particular potential benefit in younger women with dense breast tissue.

Many of the tools of digital mammography, including digital detectors and display systems for the generation of high-resolution, high-contrast, large-field-of-view images and computer algorithms for image enhancement and analysis have already been developed for space and military applications. As a result of the Diagnostic Imaging Research Branch's pursuit of the development of a Federal technology transfer program in digital mammography, an inter-agency agreement between the NCI and the National Aeronautics and Space Administration (NASA) was formalized in March 1992. This resulted in the establishment of the NCI - NASA Working Group in an effort to apply the latest technologic advances in image acquisition,

processing, and transmission to digital mammography. In July 1992, the Working Group, in collaboration with academic experts from the radiologic community, developed a program statement, which was broadly disseminated to Federal and Federally-supported laboratories in order to identify technologies critical for, and transferable to, digital mammography. Forty three technologic proposals were received in response to the program statement, and thirteen were selected by peer review process for further evaluation at the May 1993 Digital Mammography Technology Transfer Workshop held by the NCI – NASA Working Group. The conference faculty composed of industrial and academic experts concluded that the proposed technologies may solve some of the currently existing fundamental technologic difficulties hindering the development of digital mammography as a practical tool. Based on the recommendations of this Workshop, we proposed a jointly sponsored NCI – NASA Program Announcement in order to support the transfer of promising technologies to digital mammography.

Research Goals

The goals and scope of this joint NCI/NASA Program Announcement may include but are not limited to the following:

- 1) Dual use technology support. Development, assessment and implementation of dual-use technology, wherein the proposed technology will contribute to digital mammography as well as to image generation, processing and transmission, as required by NASA.
- 2) Technology transfer support, wherein medical imaging academic/industrial teams work cooperatively with a Federal Laboratory and/or Federally-funded grantee or contractor to apply a Federally developed or funded technology to digital mammography.

Examples of appropriate topics include (but are not limited to):

- 1) development and testing of digital displays for high resolution (e.g. 50-100 micrometers per pixel), high contrast (about 12-14 bits), large field of view visualization (4K by 4K, or 2K by 2K with 4K by 4K buffer) combined with practical rate of display and luminescence;
- 2) incorporation of the above described video display systems into the development of computer workstations with practical user interfaces, including multi-resolution, "region-of-interest" displays and "bright light" display equivalents;

- 3) development and implementation of novel x-ray detectors in prototype digital mammographic systems;
- 4) development and testing of novel high performance, low cost digital networks for image transmission;
- 5) high speed image processing for pattern recognition or image compression, testing of innovative computer algorithms for computer-aided diagnosis and image processing using standardized and/or pathologically confirmed mammographic image databases, image compression algorithms that do not compromise data integrity;

It is expected that multi-disciplinary teams will be formed, with participation of clinical radiologists as potential end-users of the systems developed, medical physicists who can define the technical requirements of the proposed equipment, and scientists from Federally-supported laboratories and industry who developed relevant imaging technologies for applications which may be other than digital mammography (e.g. military, space, entertainment, etc.). Participation of medical imaging technology manufacturers in these projects will be encouraged in order to stimulate early assessment of commercial viability and to facilitate technology implementation (This Program Announcement is currently active and open for applications).

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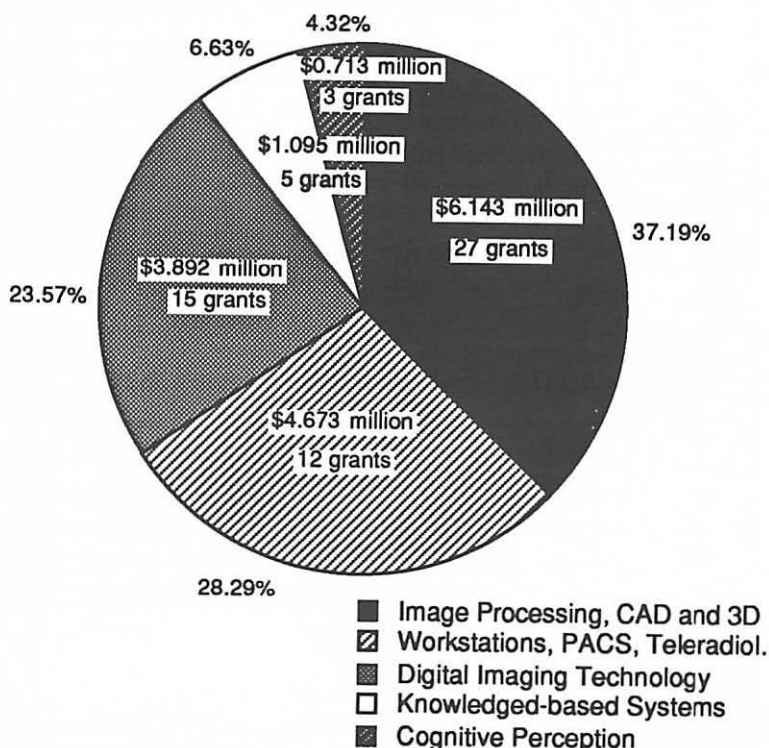
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Computer-Assisted Radiology Research Supported by the Diagnostic Imaging Research Branch, National Cancer Institute in Fiscal Year 1993



Total Computer-Assisted Radiology Research Supported by DIRB in FY93 = \$16.5 million

Total DIRB Grants Funding in FY93 = \$52.9 million

Figure 1

Mammography Quality Standards Act Implementation by the Food and Drug Administration

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I. INTRODUCTION

The Mammography Quality Standards Act (MQSA) of 1992 (Public Law 102-539) was passed by Congress to address concerns about the quality of mammography in the United States (U.S.). The Secretary of Health and Human Services delegated the responsibility of administering MQSA to the Food and Drug Administration (FDA) on June 1, 1993. To operate lawfully after October 1, 1994, mammography facilities must be certified by FDA as meeting quality standards established by the agency.

MQSA was enacted to provide national, uniform standards for equipment, personnel, quality assurance and control, reporting, and recordkeeping. This legislation applies to all facilities that provide mammography services in the U.S. except those of the Department of Veterans Affairs (DVA). The DVA is, however, working with FDA toward voluntary compliance with MQSA Standards.

The more than 12,500 facilities in the U.S. that produce, process and/or interpret mammograms must meet the requirements of MQSA. The act covers screening and diagnostic mammography. To be certified by FDA, mammography facilities must be accredited by approved private non-profit or State agencies that determine whether a facility meets the quality standards established by FDA.

II. INTERIM FINAL STANDARDS

To meet the legislatively mandated requirement of facility certification by October 1, 1994, FDA published in the "Federal Register" of December 21, 1993 (volume 58, number 243), interim final standards for mammography equipment, personnel, and practices, including quality assurance. This document also includes procedures for application to FDA for approval as an accreditation body and requirements and responsibilities of such bodies.

III. REQUIREMENTS FOR MAMMOGRAPHY FACILITIES

Clinical image review is an essential part of the facility accreditation process. Accreditation body physician reviewers who meet FDA standards assess the quality of images during initial and re-accreditations, and during audits to ensure that high image quality is maintained. Also required are an annual facility physics survey, consultation, and evaluation.

There are specific requirements for physicists who perform these functions at mammography facilities as well as for interpreting physicians and mammography technologists. There are requirements for initial and continuing education and experience, and for licensure and certifying organizations, depending on the profession of particular mammography personnel.

In addition to evaluation by accreditation bodies at least once every three years, the law requires that specially qualified Federal or State personnel inspect facilities annually to ensure compliance with standards. FDA is conducting comprehensive training and evaluation programs for inspectors to ensure that they are knowledgeable with regard to MQSA; the mammography equipment, personnel, and practices they must assess during facility visits; and ways to improve mammography quality while minimizing any disruption in the delivery of high quality services. An important goal of FDA implementation of MQSA is to improve mammography quality by helping facilities to meet standards and, in so far as possible, not by shutting them down.

IV. REQUIREMENTS FOR ACCREDITATION BODIES

Eligible organizations and State agencies must demonstrate that they meet standards established by FDA, including standards for clinical image review, physics surveys, assessing and monitoring facility compliance with quality standards, conflict of interest, investigation of complaints, and fees. The first accreditation body approved by FDA is the American College of Radiology. Approval became effective in March, 1994.

Under the interim final rules, FDA will issue a certificate to a facility when an approved accreditation body notifies FDA that the facility has been accredited by it. This certificate is valid for up to three years. If a facility has applied for accreditation to an approved accreditation body but the accreditation process will not be completed by October 1, 1994, FDA will issue a provisional certificate provided that the accreditation body has determined that the application is sufficiently complete for review. The provisional certificate is valid for up to six months. A 90 day extension is possible in certain extenuating circumstances if inability of the facility to operate would have a significant adverse impact on the availability of mammography services in a region.

V. NATIONAL ADVISORY COMMITTEE

An important provision of MQSA is the establishment of the National Mammography Quality Assurance Advisory Committee (NMQAAC). The Advisory Committee is composed of 19 individuals whose clinical practice, research specialization, or professional expertise includes a significant focus on mammography. Recent meetings of the NMQAAC have focused on proposed final standards that are expected to replace the interim final standards by the end of 1994. In addition to advising FDA on standards for facilities and accreditation bodies, the Advisory Committee is to advise the agency regarding sanctions for noncompliance with standards, procedures for monitoring compliance, and mechanisms to investigate consumer complaints.

The NMQAAC must also report on new developments in breast imaging and determine whether there is a shortage of mammography facilities in rural or health professional shortage areas and the effects of quality standards requirements on access to services in such areas. The Advisory Committee must also determine whether there will be a sufficient number of medical physicists to assure compliance with quality standards after October 1, 1999, and determine costs and benefits of compliance associated with certain legislative requirements.

VI. INFORMATION ON MQSA

Information packets on MQSA are available from FDA. A recent packet includes a copy of the Mammography Quality Standards Act; the December 21, 1993, "Federal Register" containing the interim final standards; the FDA newsletter "Mammography Matters," and additional current information. To obtain these packets and be placed on the MQSA mailing list, call 301-443-4190 and follow the recorded prompts, indicating an interest in mammography standards and leaving the name and address where information should be sent.

Answers to specific questions on MQSA can be obtained by faxing them to 301-594-3306 or by writing to "Mammography Matters" at FDA/CDRH (HFZ-240), 5600 Fishers Lane, Rockville, MD 20857.

VII. SUMMARY

FDA will be regulating the practice of mammography under provisions of MQSA. In particular, mammography facilities must be certified by FDA to operate lawfully after October 1, 1994. FDA will continue to work with the National Mammography Quality Assurance Advisory Committee and with State and Federal agencies, professional associations, mammography facilities, and consumers to improve access to high quality mammography services throughout the United States.

SESSION 16

PACS Assessment

Chair: Roger H. Shannon

IMAC Technology Assessment

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During the 1993 IMAC/CAR meeting held in Berlin, the subject of IMAC technology assessment received considerable attention. This included presentations as well as panel discussions. This should come as no surprise considering the state of the medical equipment industry.

The world market for medical equipment is at a critical period in terms of cost control. IMAC is relatively expensive and is not perceived to generate revenue as does the modalities of MRI, CT, etc. At the present time IMAC technology is reaching fruition and the IMAC participants are becoming excited about its potential. This scenario is demanding answers regarding how the users can justify the purchase of IMAC technology. Hence the need for technology assessment.

Many IMAC technology assessment discussions, such as the one in Berlin, have taken place. It is hoped that the information generated on this important subject would build over time, thereby refining the message and principles. This process is difficult to cultivate since, more often than not, each new discussion addresses the problem/opportunity from within a different framework. The reason for this is a lack of a general framework.

The purpose of this article is to propose a general framework for discussing IMAC technology assessment. It is important to treat the framework as a "strawman." That is, as further investigation demonstrates a need to modify the framework - let's do it. Only in this manner can the framework build over time as important new inputs are incorporated. A highly useful framework should not be constricting; it should have the ability to expand and grow. This process does not appear to require rocket science, only common sense.

What are the dimensions to be considered in a framework for IMAC technology assessment? Technology development certainly must be one. This would include developments of technology over time, from present technology to new technology.

A second dimension should take into account the improvement in infrastructure, or re-engineering of process. For re-engineering to become a permanent part of the infrastructure it must convert to behavior modification. This dimension therefore extends from present process or essentially no re-engineering to behavior modification.

Based on the above four possibilities exist. They include: present technology/present process, present technology/behavior modification, new technology/present process and new technology/behavior modification. We are now in a position to categorize each of the four possibilities outlined above.

Present technology/present process - this category represents no change from the present situation or "business as usual." This category may be adequate for some entities, but is certainly not the place to be in preparing for the future.

Present technology/behavior modification - this category represents doing the best you can do with what you have. During the Berlin meeting this category was referred to as "the direction of Mayo." The Mayo represents an excellent example of improving efficiency and effectivity by re-engineering process to the point of achieving behavior modification. The goal of the Mayo toward increased productivity, at any level of technology, serves as a model.

It is possible to change technology from present technology to new technology while maintaining the present process. This brings us to the category of new technology/present process. This category represents "low value." This is due to the fact that without changing process, the addition of new technology falls far short of the productivity levels that could be achieved with the new technology.

The final category is represented by new technology/behavior modification. This is the place to be to achieve the ultimate in productivity gain or bang-for-the-buck. The remainder of this paper will concentrate on this category.

Before proceeding with a discussion of technology assessment, it is necessary to consider the changing paradigm taking place in diagnostic imaging. Until recently the business of diagnostic imaging has been centered around the individual modalities. This is referred to as the "modality paradigm." During the last few years more attention has been paid to the concept of information flow on the network. This is referred to as the "network" paradigm. The change from modality to network paradigms has a significant impact on the way technology assessment is treated.

Within the category of new technology/behavior modification, it is necessary to distinguish between modality and network paradigms. The modality paradigm has been centered around "specification" based technology assessment. The factors, or purchase criteria, that are used in specification based technology assessment include:

- Technical Leadership
- Image Quality
- Throughput
- Lifecost
- Total Service

Specification based technology assessment focuses on technology factors. This is necessary, but not sufficient. An appropriate framework for technology assessment must be driven by clinical factors as well as technical factors. "Outcomes" based technology assessment adequately addresses the clinical requirements. The factors, or purchase criteria, that are used in outcomes based technology assessment include:

- Technical Performance (diagnostic accuracy; sensitivity; specificity)
- Diagnostic Impact
- Therapeutic Impact
- Patient Outcomes
- Cost Effectiveness

The category of new technology/behavior modification has been labeled as the "ultimate in productivity gain." As noted above, within this category it is necessary to measure productivity by using an outcomes based technology assessment process.

Outcomes based technology assessment ties naturally to the network paradigm. In the network paradigm information management is the central point. Information management is required to adequately address patient outcomes. Therefore the network paradigm and outcomes based technology assessment become interchangeable.

The framework presented above for IMAC technology assessment is to be considered a starting point. It embraces many of the ideas that were presented at the 1993 IMAC/CAR meeting. It is hoped that this framework can grow over time to serve the changing needs for IMAC technology assessment.

IMAC TECHNOLOGY ASSESSMENT

Low Value	Outcomes Based * * * Specification Based	N e w T e c h n o l o g y P r e s e n t
Business as usual	Direction of Mayo	
Present Process	Behavior Modification	

Initial Experience with SIENET Soft-Copy Display in a Clinical GI/GU Environment

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Mallinckrodt Institute of Radiology, St. Louis, MO

Wolfgang Rueger, Ph.D.

Siemens Medical Systems, Iselin, NJ

1. Introduction

As abdominal GI/GU radiology exhibits a strong dependence on multi-view studies for diagnosis and utilizes both fluoroscopy and projection radiography, it was targeted for potential improvements in image acquisition and case management through application of digital technologies. Renovation of the entire GI/GU facility was initiated in 1991 in anticipation of networked digital image acquisition and soft-copy interpretation. Four fluoroscopic sites were equipped with Siemens Fluorospot-H instruments and a Digiscan computed radiography (CR) system, consisting of photo-stimulable phosphor plates and a laser reader, was obtained. Integration of SIENET PACS components with these modalities was initiated in August of 1993.

Genitourinary (GU): The SIENET installation upgraded the Digiscan CR unit, in service for all GU radiological procedures for over two years. Thus, the transition had already been made from conventional film screen radiography to CR. Clinician and radiologist acceptance levels were high regarding digital images printed in dual format. Two dedicated GU radiographic rooms with tomographic capabilities and one R&F room with tomography occupied one-half of a floor dedicated to GI and GU imaging.

Gastrointestinal (GI): Three R&F rooms dedicated solely to GI imaging studies occupy the other half of the floor. One R&F room serves as a "permanent home" for endoscopic retrograde cholangiographic pancreatography (ERPC) procedures, since only in-patients are serviced on the floor. The transition then was a gradual one from a conventional film based R&F approach to GI radiology to all-digital fluoroscopy and the SIENET workstation for routine in-patient GI studies. Now, all decisions are made based on soft-copy display regarding study quality, additional views, endpoints, and image selection for printing. Radiologists at the workstations control all aspects of the examination and its ultimate recording before the patient leaves the room utilizing the SIENET system exclusively.

2. Configuration, Image Data Flow and Workload

The configuration, fully operational since December 1993, is shown in Fig 2.1. Two softcopy diagnostic interpretation workstations share the workload of 5 modalities. The Diagnostic Reporting Console (DRC) and Diagnostic Viewing Console (DVC) are equipped with 1.75 GB and 1.4 GB local image store, respectively. Both workstations are equipped with high brightness Simomed-Monitors (up to 175 fL, 20" diagonal, dis-

play matrix 1024x1024). Images are stored short term at the workstations and on the server (ISA - Image Store & Archive, 10 GigaByte capacity) and long term on an optical disk jukebox (56 5-1/4" WORM capacity, 35 GigaBytes). Two laser cameras connect to the network through appropriate interfaces (Camera Servers) to print all CR and fluoroscopic images during the initial phase of the project.

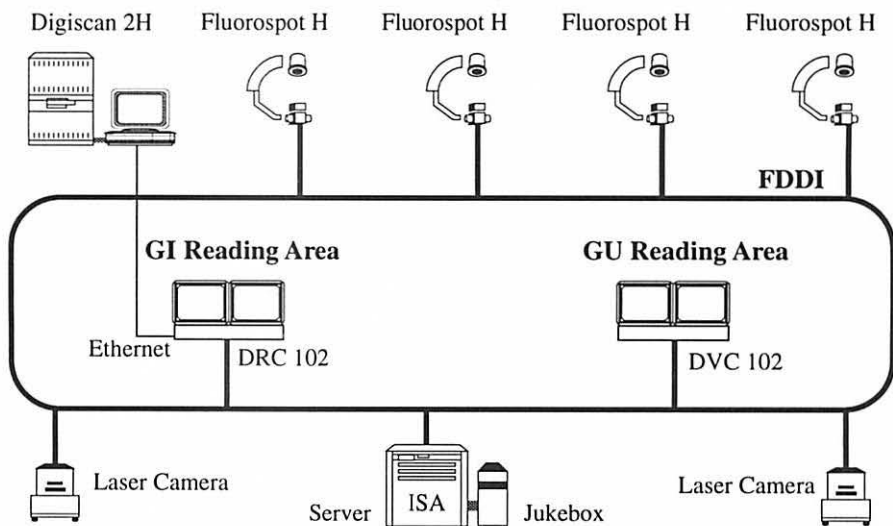


Fig 2.1: Configuration.

The image data flow is shown in Fig 2.2. A CR image is transferred from the reader to the GI workstation (DRC). The GI workstation processes the images in the background, by applying γ -correction and spatial filtering. If the GU workstation (DVC) has been identified as the target destination by the technologist, the image is forwarded automatically. Images may be forwarded from the DRC to the DVC either in the original 2K x 2K matrix or in a downsized 1K x 1K matrix. Fluoroscopic images are sent directly to the appropriate workstation. Image archiving can be configured to take place automatically, but currently takes place manually for selected images.

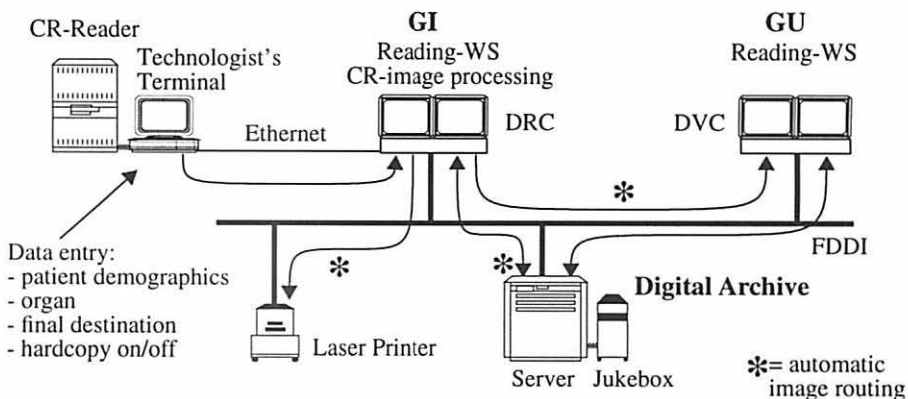


Fig 2.2: CR-image management. Image flow indicated by arrows.

Table 1 shows the workload, based on a combination of sample measurements taken in 1993 and 1994. Although GI/GU examinations consist of a mixture of fluoroscopic

	ex./ day	ima/ ex.	ima/ film	film/ exam	exams/ year	film/ year	MB/ ex.	MB/ day	GB/ yr.
Fluoro	18	20	6	3	5,148	17,160	15	270	77
CR	9	10	1	10	2,574	25,740	75	675	193
Totals	27				7,722	42,900		945	270

Table 1: Workload (1 Fluoro image = 0.75MB, 1 CR image = 7.5MB)

and radiographic images, the breakdown of the workload is shown per modality for comparison with the storage capacity necessary. Fluorospot images are 880 x 880 x 1 Byte (256 gray scales), or 0.75 MB. CR images, for 14" x 17" cassettes, are 2144 x 1760 x 2 Bytes (10 bits, or 1024 gray scales), or 7.5 MB. The GI/GU facility is operational 5.5 days a week.

3. Timing Measurements

Fluorospot images are sent from the acquisition console to the workstation at the rate of about 10 seconds per image. A series of 20 images requires 3 minutes and 30 seconds.

Table 2 shows timing measurements for CR images. The SIENET Digiscan system

<i>Digiscan CR Images</i>	First Image	Subsequent Images	Stand-Alone Digiscan
Cassette Insertion:	0:00	every 0:15	0:00
Image on DRC:	2:45	every 1:30	----
Image Routed to CamSv:	3:20	every 1:30	----
Image Routed to DVC:	3:30	every 1:30	----
Hardcopy Processed:	7:15	every 1:45	3:00

Table 2: Digiscan Timing Measurements

is configured such that images flow from the reader to the technologist's terminal, where patient and image data is integrated, to the DRC, where the image data is processed using an unsharp mask algorithm. From the DRC, the images are automatically forwarded to the Camera Server and to the DVC viewing console.

In the stand-alone Digiscan CR system, images were forwarded directly to the printer from the reader, and the hardcopy was available in approximately three minutes. In the SIENET Digiscan system, images are available for viewing on the DRC in 2 minutes and 45 seconds and on the DVC in about 3 minutes and 30 seconds. Under peak load, images flow through the system about every minute and a half except at the printing stage, where films are produced at an average of one every 1 minute and 45 seconds.

Archive retrieval times, summarized in Table 3, depend upon the location and modality of the image. The ISA stores both raw and processed CR data so that images can be reprocessed if desired. From the high speed disks on the RAID array of the ISA, CR images can be retrieved in about 37 seconds, and a typical Fluorospot study of 20 images can be recalled in less than one minute (2.75 seconds/image). From the jukebox, a CR image takes two and one half minutes to retrieve, and an examination of 20 Fluorospots takes about one and one half minutes (7.5 seconds per image).

	<i>Images on ISA</i>	<i>Images on Jukebox</i>
20 Fluorospot Images:	0:55 (2.75 sec/image)	1:30 (7.5 sec/image)
Single CR Image (15MB ¹):	0:37	2:30

¹ 7.5 MB raw + 7.5 MB processed data

Table 3: Archive Retrieval Timing from Workstation

4. System Strengths

Image flow:

The most important feature of the Digiscan for GU Radiology is its ability to route "down-sized" images to the DVC viewing console. The CR reader acquires a nearly 2K x 2K image matrix, consisting of 7.5 MB. The DRC "shrinks" the image to 1K x 1K using an averaging algorithm before routing to the DVC, wherein display and processing procedures are dramatically improved. Although not studied, the degree to which image quality is diminished due to down-sizing is relatively insignificant for GI/GU contrast studies and is far outweighed by the greater increase in system viewing performance and case management.

Images which are available from the ISA archive have greatly increased the accessibility and ease of retrieval of examinations. Images from previous weeks or months, which normally would have to be brought from the film library, can be obtained electronically within a few minutes. Often images from the same day are retrieved for review with clinicians after the hardcopies have left the floor.

Time and film can be saved by selective printing. Fluoroscopic exams (typically consisting of 20 images or more) are often culled by the user to a subset of images which tell the diagnostic story and do not include superfluous or non-diagnostic views. A variety of print formats exist (from 1-on-1, 2-on-1, up to 25-on-1) which allow the user to further reduce the total number of films produced without losing any images. Of course, larger hard copy images are easier to interpret, but we have found that the 4-on-1, 6-on-1, and 9-on-1 film formats provide the best balance between image size and film reduction for GI and GU fluoroscopic images. In our early experience it has been difficult to determine actual film saved to this point, but it is clear that the potential for significant savings exists and will be fully realized in the near future.

Image Processing and Viewing:

The ability to set the parameters for CR image processing is extremely useful. The inherent system default parameters for GI and GU images were not optimal for our

camera/film combination. By altering the parameters which effectively control brightness, contrast, and edge-enhancement individually, the quality of tomographic and plain CR images was markedly improved. Hardcopies are printed with two different algorithms, one which mimics a non-linear, "film look" (preferred by clinicians) and the other a linear, edge enhanced view.

Gray scale inversion is another frequently used processing technique. The conspicuity of structures can be improved if the image or contrast material is viewed as black instead of white.

Although the user can easily alter the "display mode" (the way in which images are presented on the monitors), a single mode works well for both GI and GU exams from either modality. Both viewing stations have two monitors; the one on the left contains 25 small "token" views which display an overview of the exam. Clicking on a particular token view displays that image in full view for interpretation on the right-hand monitor. Although we initially used other displays, such as 4-on-1 on both monitors, we found this mode to be easy to use and sufficient for all types of GI and GU exams.

5. Areas For Improvement

Variance between Hard and Soft Copies:

The biggest problem to date has been the large discrepancy between the hard copy (film) and soft copy display. It has been very difficult to consistently achieve visual parity between the two techniques. Image quality on the monitor has been very consistent, as the monitor is the only variable in the display chain. The hard copy, on the other hand, has been subject to fluctuations in the laser camera and in the processor. Compounding the issue is the fact that both camera and the film are products of different vendors and do not easily calibrate correctly.

User Interface Refinements:

Areas where current improvement efforts are focused include peak load period slowdowns. The system is slow to accommodate commands and responses when subject to peak loads. "Multi-tasking"--receiving, processing, printing, routing, and displaying images simultaneously--is expected to improve with software revisions and further decline in production of hardcopies.

The "Worklist" is a window which contains the information about locally stored patient studies and is the vehicle through which images are managed and displayed. In general, there could be more useful information immediately available in the Worklist, and certain image file operations are cumbersome (*e.g.* individual Digiscan images must be "opened" and then "closed" before they can be "merged" with other images).

Although there has been very little down time due to equipment failure, the occasional need for re-starting application software or re-booting the host computers exists. In the first three months of 1994, a total of 18 re-starts and re-boots were performed (ave. of 1.5 per week). However, the system recovery is very robust as no images have ever been lost.

Archiving:

The expense of optical disks has limited our ability to archive all examinations. We currently only archive fluoroscopic examinations due to their smaller data size (0.75 MB/fluoro image vs 15 MB/CR image). A number of factors which will shortly come into play should allow us to archive all CR images as well. First, a loss-less compression

algorithm on the ISA will reduce stored data by a 2-to-1 factor once released by the manufacturer. Second, archiving "down-sized" CR images, already smaller by a factor of four, using the loss-less compression would effectively reduce Digiscan data size by a factor of eight. Finally, archived CR data could be cut in half by saving only the processed image data if the conserved resources justified the loss of ability to reprocess Digiscan images.

6. Summary

Our experience with an all-digital GI/GU department has been very encouraging during the first four months of its existence. Although film production certainly has not ceased, the potential for filmless operation exists. The major obstacle to a filmless GI/GU environment is the demand for a medical record--a film--by the referring physicians and community standards of practice. Access to additional soft-copy display resources may mitigate this requirement. We will continue to explore the existing ways in which the digital GI/GU department can save time and conserve film.

Experiences with the Implementation of a Speech Recognition Radiology Reporting System for Use by Residents in a Busy Emergency Room Setting

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Speech recognition systems are rapidly establishing themselves as useful tools for the rapid, efficient generation of radiology reports. Just as with any other type of sophisticated audio-visual interactive device, these systems function best when they are used on a regular, daily basis by a single, dedicated radiologist in a quiet, controlled environment. Diametrically opposite to this ideal system placement milieu is that of the busy urban emergency room radiology department, in which multiple radiology residents each rotate in to use the system on an average of once a week amid hectic, noisy surroundings. However, this is precisely the environment where the need for a speech recognition reporting radiology system is most pressing. In order to bring these benefits to our very busy emergency area, a number of factors had to be addressed:

- **A large, ever-changing pool of periodic resident users of the system, which had the potential to make training difficult** -- the residents varied widely with respect to their individual skill and interest levels
- **Noisy environment, which had the potential to interfere with the voice-recognition function of the system** -- our emergency area can be a very loud and hectic place at times

- **Stressful, hectic 24 hour-a-day environment with many distractions and interruptions**
- **The potential for a large amount of physical wear-and-tear on the equipment, stemming from continuous extended periods of use -- this placed an additional stress on the system components**
- **Trepidation among the residents about learning to use the system at the same time that they were about to undertake a program of busy night call**

Since the potential benefits of the system (instant production of legible typed reports on a 24 hr X 365 day basis) far outweighed these possible problems, a number of specific measures were taken, which included:

- **Intensive, custom-tailored training and support of each of the large pool of resident users of the system -- by adapting the methods so as to suit the particular needs of each resident, we were able to provide each person with whatever levels of help and encouragement he/she required**
- **The designation of one of the residents as a "superuser" who was able to act as an additional resource for the others -- the application of the "superuser" concept served as a powerful tool for gaining acceptance of and facility with the system among the residents**

- The publication (by the "superuser") of a system newsletter which served as a powerful morale-builder and skill reinforcement tool -- this was one of the methods employed to further enhance system embracement among the residents
- Modification of the system to render its operation simpler and more straightforward under hectic conditions -- some operational elements were modified to make the system easier to use in its ER surroundings
- Ready access to spare parts for the system -- we set up on-site stockpiles of those items which we found to need (when used in this environment) frequent replacement/repair
- Physical redesign of the emergency radiology reading area, along with the installation of extra soundproofing material -- this helped to bring the ambient noise down to more comfortable levels

These measures have allowed us to successfully implement the system in our emergency room radiology department, where we have found it to be a very effective tool. The lessons which we have learned during the ER installation will greatly aid us in our planned expansion of the system to other areas of the department.

Preclinical Testing of a Cost-effective Digital Modality Diagnostic Workstation

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I. INTRODUCTION

Diagnostic workstation design remains a challenge in the widespread deployment of PACS.(1) The single monitor working prototype of a diagnostic workstation for digital modalities described previously has been expanded to three monitors.(2) The hardware platform is a Macintosh Quadra 840AV with a Dome Hydra display system. Monitor resolution is 1024x1280. The basic concept is to emulate a multi-panel film alternator with relatively less expensive medium resolution monitors, backed by abundant off-screen memory and an effective user interface. This enables the radiologist to see many images at once, at reduced resolution, but with instant access to full resolution data. The full clinical system will have six or twelve monitors.

Prior to placing this system in clinical operation, preclinical evaluation of this design and implementation is being performed by the Neuroradiology staff. The principle criteria are diagnostic accuracy, workplace efficiency and user-friendliness.

II. MATERIALS AND METHODS

The PC platform of the multimonitor prototype is a Quadra 840 AV, with a prototype Dome Hydra display system capable of driving three portrait monitors of 1024x1280 resolution. The Hydra has 32 megabytes of off-screen memory per monitor. The monitors used are 23 inch diagonal Monitor Technology (approximately the size of 14x17 film).

Software implementation was performed with the Macintosh Operating System and Toolbox, Think C with Objects (Symantec Corporation), and the Dome Hydra Display System Library.

This prototype diagnostic workstation is connected to the UCSF PACS system via Ethernet using TCP/IP. All CT and MR studies are acquired by the PACS via the DICOM standard and are archived appropriately.

Diagnostic accuracy for gross discrepancies is being assessed by a controlled study of comparative interpretation of between 50 and 100 sequential current CT and MR

studies read from film and off the workstation monitors (softcopy interpretation), in order to obtain an initial evaluation of clinical acceptance. Only studies having no prior comparisons will be used in this phase, to eliminate the variable of how best to input and display prior studies available only on film.

In addition to diagnostic accuracy, workplace efficiency is essential to the clinical acceptance of this project. This is being assessed by recorded times of interpretation, including the process of report dictation, similar to prior workstation evaluations. Of particular interest will be the contribution of the user interface, use of the workstation tools, and the methods of accessing the full resolution data. Subjective evaluation of user fatigue will also be attempted.

III. RESULTS

Technical results:

Once loaded into off-screen memory, the time to display a full resolution 512x512 image on mouse command is approximately 30 milliseconds using the Dome system configured as described. Cine or page mode of up to 50 512x512x12 bit images can also be performed at up to the same maximum frame rate. The loading of images from local workstation magnetic disk to the Hydra offscreen memory occurs at 4 seconds per 16 512x512 images, or 250 milliseconds per full resolution image. Full bit depth is maintained.

The graphical user interface prototype is promising. Image control is largely via local pop-up menus. The workstation pop-up menus and controls are shown in Table 1.

On this platform, there is potential for contention or conflict between interaction with the GUI and network communications. Analysis of this problem, and the role of the Folder Manager(3) in minimizing conflict, will be presented at the conference.

Clinical Results:

The simulated clinical evaluation described above is in progress, and results will be presented at the conference.

IV. DISCUSSION

This project tests at least three hypotheses:

1. Can a Macintosh or other personal computer system provide an adequate platform for a diagnostic workstation that is accurate, efficient and user friendly? (4)
2. With appropriately designed software, and the use of abundant, inexpensive off-screen memory, can medium resolution monitors, which are much less expensive than their high resolution counterparts, provide appropriate diagnostic accuracy?

3. Can the Folder Manager protect the radiologist user from interference from network communication of studies to the workstation?

With the increasing power of personal computers there has been a convergence with the capabilities of low-end workstations, in both performance and price. Why then, since the basic computer represents only a small portion of the total system price, should a clinical workstation be built upon this platform? The best answer is that the Macintosh is commonplace in academic radiology departments, and its GUI are well known and unmatched for user-friendliness, even in comparison to Windows and X-Windows. In addition, at the present time, multi-monitor display drivers are not economically available for workstations.

V. CONCLUSIONS

This project demonstrates that it is possible to build a powerful diagnostic workstation for digital modalities on a PC platform (Macintosh), and that a multi-monitor system that emulates film presentation, yet allows for newer methods of image presentation such as page or cine mode, can be effectively performed with medium resolution monitors. In the future, with increasing processor speed, more of the specialized functions of the Dome system may be able to be performed in memory.

The feasibility of creating a diagnostic workstation on the same order of cost of a mechanical film alternator has been demonstrated. It also appears promising that, with proper software, attention to the effectiveness of the user interface, and technology such as the Dome Hydra system, that expensive 2K monitors may not be necessary for accurate soft copy interpretation of CT, MR and ultrasound.

Further evaluation needs to be performed regarding network contention and communication speed prior to placing this system in clinical service, due to the fact that the Macintosh platform is not a true multitasking machine.

Pending the successful completion of this phase, including modifications based upon the testing, a full six or twelve monitor diagnostic workstation will be constructed with this architecture, and placed in clinical service for soft-copy interpretation. Initial feedback regarding the user-friendliness of the GUI has been positive. If successful, this project will mitigate one of the cost barriers to the deployment of PACS.

Acknowledgements

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Todd Bazzill, B.S.E.E.T. provided essential technical support. Laura Snarr assisted in graphics and presentation.

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Table 1. Features of the Workstation Graphical User Interface

Separate control display

Access: password protected

Local storage patient list: medical record#, name, age, sex

Sort: None currently

Selected patient: list of studies, dates and time, sequences

Format selection: 16 on 1 to 1 on 1

Mouse and popup menus:

left button: instant full resolution zoom x2

middle button: select slice click on/off (for subset editor)

right button: access toolkit popup menu at current mouse location

window/level:

change settings

(nested to presets lung, bone, ST, brain)

restore default

apply to selected sections

apply to sequence

access W/L tool (bar)

512x512 mode (4 on 1 display at full resolution)

stack(= cine or page mode)/tile switch

(Currently no mouse control of rate)

Output image

copy to clipboard

print image

send to personal Mac via network

subset editor

large arrow icons at bottom of display: next page/next image if cine reports for prior studies available on WS (via HIS)

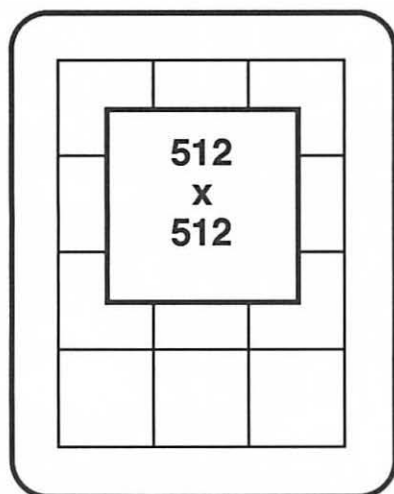


Figure 1. Overlay of full resolution image pane on low resolution images

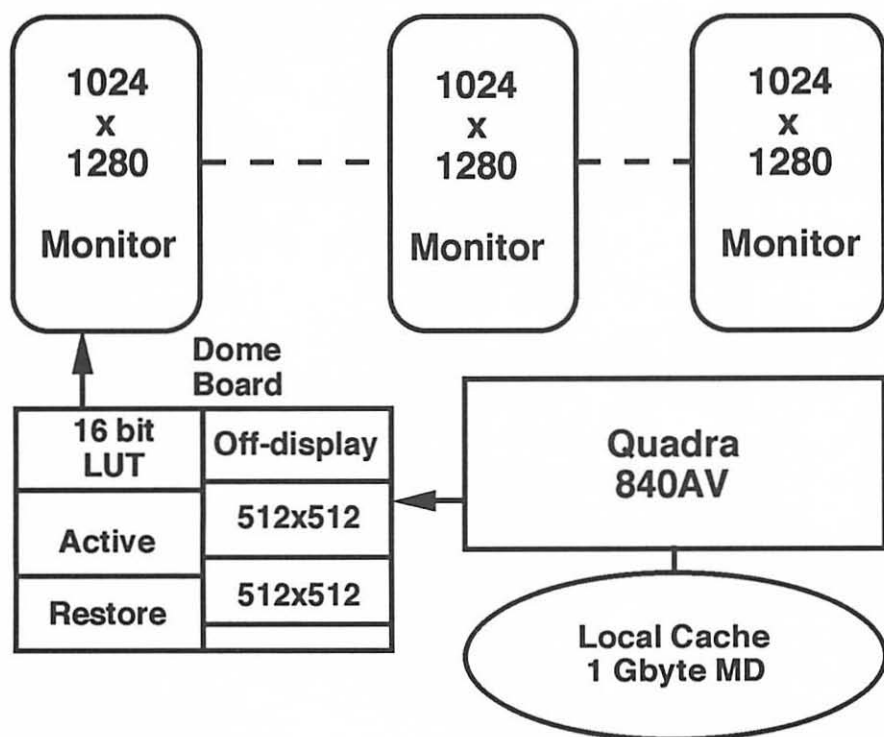


Figure 2. Digital Modality Multi-Monitor Workstation Architecture

Digital Versus Analogical Images in Abdominal Radiology

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INTRODUCTION

The technological advances in digital radiology represents a great innovation in the adquisition, viewing, tansmission and archiving of the images. The implementation of digital systems for conventional radiology allows digitization of any image in a radiological department. In such a way, it is possible a full employment of the image transmission and archiving systems².

We can find in the litterature many reports about the different features of digital image applied to conventional radiology of thorax , musculoskeletal system and pediatrics^{1,2,4}. But few studies have dealt with digital image and plain abdominal film⁵. We are studying the usefulness of digital systems applied to normal and pathological plain abdominal films. In this study we have evaluated computed radiography, laser film digitizer and teleradiology.

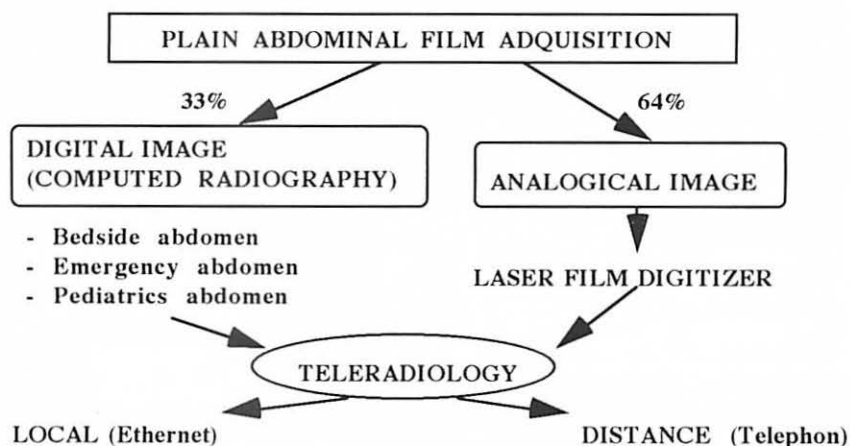


Figure 1.- Plain abdominal film adquisition. IMACS (Image Management Archiving Communication System). Dept. of Radiology.

In our department, 33% of plain abdominal examinations are computed radiographies (bedside abdomen, emergency examinations and pediatrics) and 67% are conventional films (Figure 1).

We have already noted some advantages of the computed radiography such as the reduction of the radiation dose (Figure 2), less number of repeated examinations due to errors of the radiological technique, the image can be postprocessed at the workstation, good quality of the images in the bedside abdomen, the images can be teletransmitted and loaded in the PACS (Picture Archiving and Communication System)^{2,3,5}. We are trying to demonstrate in this report that the analogical images from normal plain abdominal films can be accurately digitized and teletransmitted.

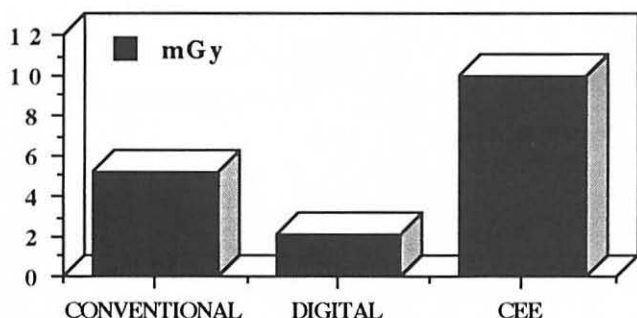


Figure 2.- Radiation dose on the surface in abdominal conventional and computed radiography. European Community reference in AP abdominal projection: 10 mGy.

The aim of the present study is to evaluate the diagnostic reliability of normal plain abdominal digital images, obtained by radiographic film digitization and teletransmitted with and without compression.

MATERIAL AND METHODS

The quality criteria for radiological images established by the European Community have been followed. And from a group of 200 examinations, 40 normal plain abdominal radiographs were chosen by two radiologists.

The analogical images were processed by a laser film digitizer system and they were teletransmitted via phone modem to a length of 11 km., by point to point line with variable compression 3:1 - 6:1, and without compression (Figure 3). The digital images were displayed in workstations of 1280 x 1024 x 8 bits. resolution (TABLE 1).

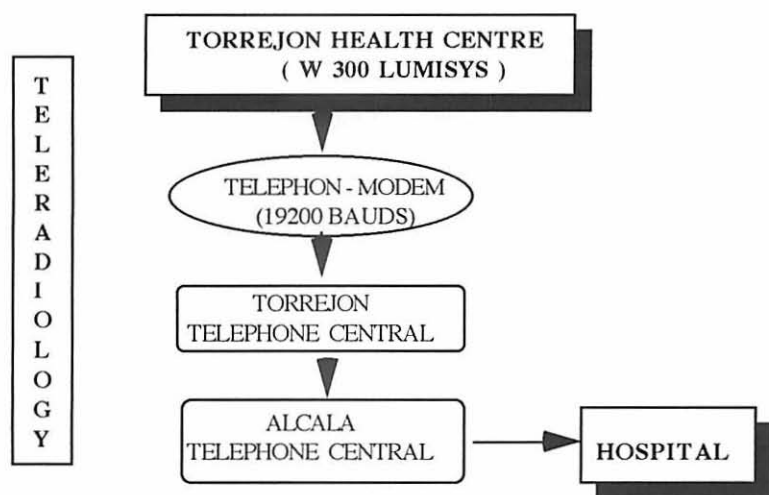


Figure 3.- Telephone teletransmission at the health area.

Four groups of abdominal images have been studied: conventional films, digitized images and teletransmitted with and without compression images. Three radiologists read the images individually in three different sessions every one month.

TABLE 1.- TECHNICAL CHARACTERISTICS

Laser film digitizer

Laser spot size	135 m.
Matrix size	2048 x 2487
Spatial resolution	3584 pixels / lin
Contrast resolution	12 bits
Optical density range	0 - 3,5
Scan time	3 min.

Teleradiology system

Telephonic communication modem	19200 bauds
Distance	11 Kms.
Compression rate	3:1 - 6:1
Time to transmission with compression	4 min.
Time to transmission without compression	4 min. 5 sec.

Display workstation

Monitor size	19"
Resolution	1280 x 1024 x 8 bits
Horizontal frequency	48.5 Hz
Vertical frequency	60 Hz
Memmory	330 MG, 300 exams.
Access time	8 sec.

Fourteen anatomical features of the abdomen have been considered. These data comprised fat planes, gas pattern and bones (Figure 4).

The statistical analysis was done following the chi square test.

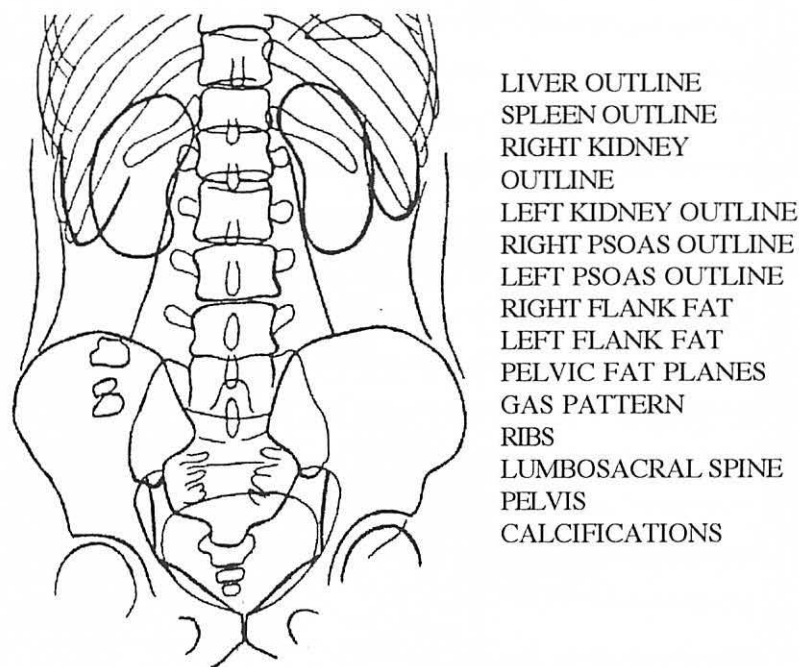


Figure 4.- Anatomical features considered on plain abdominal film.

RESULTS

Better visualization of gas pattern in all digital images and poorer identification of flank fat only on teletransmitted pictures with compression ($p < 0.005$) have been observed. For the rest of the abdominal structures, the statistical analysis did not show any significant difference between analogical, digitized and teletransmitted images (Figure 5).

The lost of information about the flank fat, observed in the teletransmitted images with compression, was not present in the teletransmission not compressed. The times required for the teletransmission in both modalities have not been significantly different.

The changes on digitized image made at the workstation allow a better identification of the anatomical structures studied, but these findings are not statistically significant.

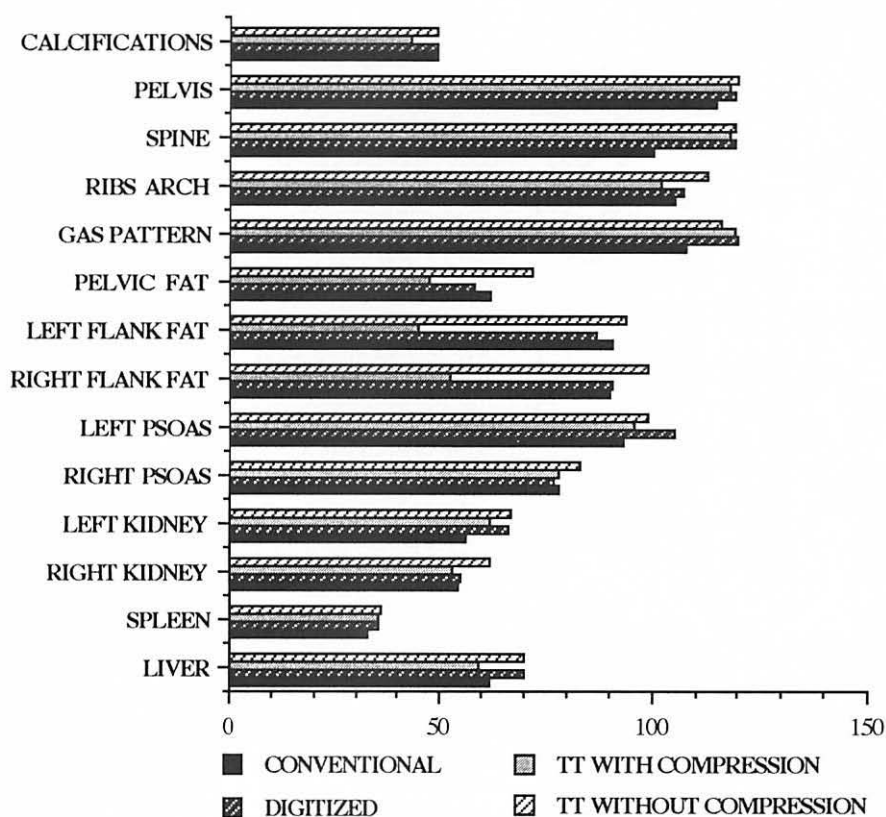


Figure 5.- Anatomical features well displayed in normal abdomen.

CONCLUSIONS

- 1) The normal abdominal digital images obtained by laser digitizer do not lose any significant radiological information.
- 2) The abdominal digital images teletransmitted do not lose significant radiological information, with the exception of the flank fat in the images compressed.

3) The anatomical structures of the normal plain abdominal examinations are more clearly observed in the digitized images after the changes made at the workstation, although these data are no statistically significant.

4) After these data, we consider the teletransmission by telephone of great value both for the communication of interest cases to other radiologists and for the long-distance control of routine examinations.

5) Considering these data and the features already observed in computed radiography, we conclude that the digital image is more useful than the analogical one in plain abdominal radiography.

ACKNOWLEDGMENTS

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Parameters Required to Evaluate a Filmless Imaging System

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Many members of the radiology community have been predicting the imminent arrival of large scale Picture Archiving and Communications Systems (PACS) for at least a dozen years. It now appears that we will have to wait until the 100th anniversary of the discovery of the x-ray in 1895 before even a handful of radiology departments become filmless. The reasons for this are numerous and include the high cost of technology, lack of satisfactory workstations, delays in developing and adopting interface standards, and the inertia which invariably develops in any system which has been in use for several decades.

Despite this inertia, several radiology departments are reporting plans to include some form of PACS in their medium and long range forecasts, or are actively shopping for components or large scale systems. During a session at the 1993 meeting of the RSNA, a majority of attendees indicated that they had plans to implement some form of PACS in their hospitals during the next ten years. Factors promoting this optimism include significant improvements in workstations, networks, more cost effective storage technology, the increasing need to link hospitals to outpatient clinics and other medical centers, and perhaps most significantly, the existence of a small number of PACS implementations.

The estimated cost to install PACS at all of the 170 VA hospitals is approximately one billion dollars. The installation of PACS in other large hospital networks, academic facilities, and community hospitals during the next ten to fifteen years will cost many billions of dollars, even with the anticipated decreases in the price of technology. With imaging equipment, a department was able to justify the purchase of a new unit on the basis of perceived or proven clinical value, needs of the community, or by demonstrating that the machine would generate sufficient revenue to show a profit. With PACS, these justifications have not been validated. For hospitals to justify a large investment in PACS, they will

have to present empirical data which demonstrate that the PACS can be feasibly and reliably implemented in a hospital setting and will result in significant benefits (cost and quality) in the provision of patient care. To assist in the validation of PACS, data from baseline studies are critically needed to evaluate the quality of care, economic, political, social, and technological impacts of large-scale PAC systems and their components. These data should assist other radiology and hospital decision makers in deciding if and when to convert to digital imaging, which areas of the hospital or department to change first, and how to distribute the costs among radiology, other departments, and the hospital.

The VA Baltimore Medical Center which opened in January 1993, has installed a large scale PACS as well as a fully integrated Hospital Information System/Radiology Information system. This includes a second separate integrated global hospital PACS which accepts images from other areas of the hospital such as pathology, dermatology, cardiology, GI endoscopy, bronchoscopy, and the operating rooms. For the past six months, more than 95 percent of images read in radiology and over 90 percent of images seen outside of radiology are viewed as "soft-copy" using electronic imaging workstations.

Multiple methodologies were considered for baseline data collection to measure the impact of PACS prospectively. One was to compare selected parameters in the new hospital after the PACS became operational with those in a comparable VA facility that continues with a film based system. The advantage of this approach is that a large amount of data can be collected in parallel in both institutions. This approach will probably be used to some extent in our evaluation; however it is difficult to find a truly comparable hospital and supervise the collection of data in a controlled fashion. The plan that we preferred was to compare selected parameters within our new medical center before and after the installation and routine use of PACS. We chose to begin the collection of baseline data approximately six months after the new medical center opened to allow the staff to become accustomed to the new facility. We began collecting the "post-PACS" data during a transition phase after approximately three months of operation with digital workstations with film available but rarely utilized. The next phase of data collection will be approximately six months later when soft-copy operation (i.e. filmless radiology) is complete.

Because of the extent of the impact of a large-scale PACS on departmental and hospital functions, the parameters required to evaluate a filmless imaging system must cover a wide spectrum. The parameters may be divided into four major areas of analysis: operational, technical, educational (including clinical acceptance of the system), and patient care outcome studies.

Operational Parameters

In addition to producing excellent image quality, a radiology department must be able to acquire images of a patient within a short period of time after an examination is requested. These images must be readily available to radiologists and clinicians who need to render opinions or make decisions based upon those images. The department must also produce accurate reports that are available as soon as possible after the examination has been performed and are readily accessible.

Operational parameters measure throughput in the radiology department, the throughput of patients in the remainder of the hospital, utilization of imaging services, reliability of image retrieval, accessibility of images and reports and resulting utilization of clinician's time, and requirements for personnel, space, and supplies required for operation. These parameters are related to an assessment of the economic implications of PACS for an imaging department and hospital.

The productivity of radiologists can be measured as the time required to interpret and report various types of imaging studies. This parameter depends upon whether radiologists are required to "hang" their own films or whether a file room clerk arranges them on an alternator, to what extent previous images are routinely reviewed, how often prior reports are read, the extent to which a "hot light" or workstation tools such as magnify and zoom are used, and the amount of radiologist fatigue. Technologist productivity will be affected by the amount of time required to print films or send images to PACS and by changes in the percentage of repeat examinations performed due to unsatisfactory images. Hospital throughput parameters include the average number of patients seen in the emergency room and in the clinics per hour and the average length of stay. Parameters such as length of stay vary considerably during the course of a year and thus it will probably be difficult to measure small changes in these as a result of PACS. Also, it is difficult to control for other factors such as the influence of health care reform and changes in patient mix.

Utilization of imaging services can be measured by the volume of imaging studies ordered per patient for inpatients and outpatients and the breakdown of types of examinations requested. It is not clear whether the predicted increased availability of services can be measured by the volume of imaging studies ordered and the breakdown of types of examinations requested. It is not clear whether the predicted increased availability of images with a PACS will increase or decrease the number of studies ordered but this could have a major impact upon the decision to convert to filmless imaging. Additionally, the number of times that each radiology film or PACS image is retrieved should be measured

The reliability of image retrieval includes the accessibility of images. Thus important parameters to measure include the percentage of images requested that can be retrieved, the average time to retrieve selected images, and the percentage of imaging studies that are not interpreted by a radiologist within certain periods of time or are lost and are never officially interpreted. The average time from when an image is produced until it is dictated by a radiologist and the average time from when an image is obtained until it is seen by the ordering clinician should also be recorded and analyzed according to the type of examination.

In addition to measuring the average amount of time required for a clinician to retrieve an imaging study, the relative amount of time that a clinician or medical team spends retrieving radiology images per day should be measured since multiple images may be retrieved at one time increasing the efficiency of retrieval of films. The relative amount of clinician time saved by PACS is a critical parameter to measure when assessing the impact of filmless radiology. Even small improvements would add up to potentially huge economic benefits of PACS. This assumes that the time saved with PACS would result in increased time for patient care, administrative responsibilities, or education.

The evaluation of the PACS must include an assessment of personnel, space, equipment and supplies required with conventional versus filmless operation. The largest increased expenses with PACS will be attributable to the capital investment and depreciation of equipment and the service contracts required for its maintenance. The additional expenses for personnel required to manage and operate the equipment and the space required for the PACS computers and other equipment and supplies (e.g. optical disks) should be offset by decreases in personnel required for film management, significant decreases in space required for storage of images, and major decreases in the cost of films and related supplies. The measurement of these parameters has been well described in the literature.

Technical Parameters

Technical parameters should measure the performance of the hardware and software of the PACS. Image quality and the enhancement and other ergonomic features available, and frequency of their use at the workstation should be compared with a conventional film-based environment. The performance of hardware and software can be determined relatively easily and includes measurements of the time to retrieve the image from long and short term storage, the time to display an image, and the time to perform image manipulation such as rotation, magnification and area determination. It also includes measurement of monitor performance such as luminance, brightness uniformity, resolution, linearity, etc.

Physical image quality can be assessed in a number of ways. The contrast and spatial resolution that can be viewed at the workstation can be measured using a phantom or test pattern. The differences in brightness of the monitors and a conventional viewbox can be compared and the implications of different levels of brightness for physical image quality and speed of image interpretation can be evaluated.

The best way to measure diagnostic image quality is to perform prospective ROC studies using specific modalities for specific disease entities to compare the relative ability of soft-copy and hardcopy interpretation with respect to confidence and accuracy of diagnosis.

The utilization of workstations throughout the hospital should be measured to determine the number of images viewed per period of time, the hours that the workstations are used, and the functions used at the workstations. This should help in the assessment of the network and computer requirements of a filmless radiology department and the tools that should be available to users in a main menu or in supplementary menus.

Educational Parameters

Assessment of the training process for PACS and clinical acceptance of the technology (or lack thereof) is particularly important to document because of the large effort required to teach what represents a major change in the way in which images are viewed and the options available for image manipulation. This training process is particularly difficult in an academic medical center in which there is a large turnover of physicians. Thus, one of the most important educational parameters is the amount of time necessary to formally train users of the system and the amount of formal training versus proficiency with the system.

It is important to acknowledge that a significant percentage of users may not undergo formal training for a variety of reasons and thus their proficiency and relative percentage in comparison to users that have been trained must be assessed. Additionally it is important to assess the "learning curve" for both clinicians and radiologists who use the PACS.

The impact of PACS on education in a hospital environment should also be measured. One of the most interesting consequences of filmless radiology is the potential for improved communication between radiology and referring services. Ironically, accessibility of images and reports through PACS may decrease personal contact with radiologists by reducing the number of visits by clinicians to the radiology department. Thus it is important to measure the number of consultations by visits to radiology or by phone and the length of each

consultation. These observations are not only important in education and patient care, but may also have implications for the efficiency of physicians.

The role of an imaging department in education extends not only to radiology personnel, but to referring clinicians, other hospital staff and to patients. The extent to which PACS improves student, housestaff, radiologist, clinician, and other hospital personnel education is a function which should also be assessed if possible.

Outcome Studies

The most difficult and arguably the most important parameters to measure in assessing a filmless radiology system are those having to do with patient care outcomes. The outcome measurements that are most critical reflect the role of the imaging department in patient care. The ultimate outcome measurement is the overall quality of patient care and an evaluation of the role of PACS in keeping patients healthy and restoring those who are not to good health. Thus the ability to examine patients in a timely manner, to reach an accurate, confident interpretation, and to report the interpretation to the referring clinicians, determines the effectiveness of a PACS and the relative contribution it makes to an imaging department.

Another role of the radiology department is to market the department to referring clinicians. Thus it is important to measure satisfaction of the delivery of imaging services as perceived by the referring physicians. The relative volume of patients referred to the imaging department may indirectly reflect the perception of the quality and importance of imaging services. The accuracy of image interpretation as measured by correlation with pathology and surgical results and long term follow-up are also important measurements in the assessment of outcomes related to filmless imaging.

Conclusion

In conclusion, the evaluation of a filmless imaging system requires a comprehensive approach which takes into consideration the many complex responsibilities and functions of an imaging department. There have been few detailed studies of large scale or filmless PAC systems. The task is complex and the very few large scale, fully operational PACS have existed for relatively short periods of time. It is important to emphasize that PACS represents a totally different way of managing and presenting imaging studies. The relatively broad spectrum of types and degrees of improvements that PACS confers will vary depending upon the operations of each imaging department, the geographic location, the type of health care system under which it operates, and the hospital's

general mission. Additionally, the savings that occur with a large scale PACS may not necessarily be achieved at all with a smaller PACS or for a small section of a department that does not allow universal access or does not permit true filmless operation. For example, assessment of savings with an intensive care PACS application may underestimate the cost savings that one might achieve in the ICU with complete filmless operation. An ideal assessment of the impact of PACS should consider improvements that could be made to the management of a film-based department **without** the use of PACS technology. The impact of PACS should be evaluated at several levels including the section, department, hospital, and perhaps most importantly, at the regional or large hospital network level. Finally, it is likely that well designed prospective studies of filmless imaging will have a large influence on the acceptance and dissemination of PACS over the next ten to twenty years.

SESSION 17

DICOM/LAN

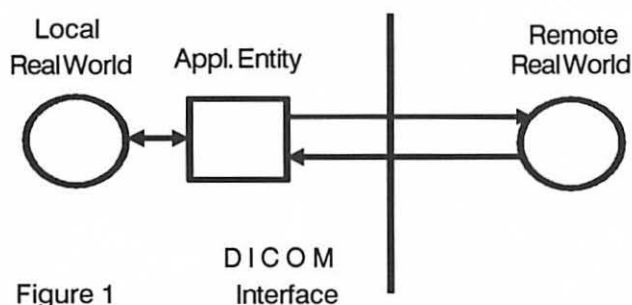
Chair: Steven C. Horii

The DICOM 3.0 Standard and the Real World

Robert Hindel

R H Consulting, Orange, CT

The term "Real World" does not refer to the colloquial meaning of real world as distinguished from the unreal world of science fiction or even of an ideal world of romantic literature. It is a specific term illustrated on page 8 of part 2 of the DICOM standard (1) . The illustration is copied below



The "Real World" initiates an action which leads to a communication event based on the DICOM standard. It is implied that the part of the "Real World" which triggers this event is by itself not compatible with the standard. In terms of physical reality the part which is compatible is obviously real and maybe combined with the part with is not compatible. More specifically a workstation contains software which is compatible with the standard and software which is not.

A more likely implementation connects a " Local Real World " to a " Remote Real World " via two corresponding Application Entities (AEs).Such situation was demonstrated at he InfoRAD exhibit at the

RSNA 1993 and before that in 1992. Some twenty companies produced workstations called Demonstration Nodes (DNs) which were capable of communicating with a test suite (called Central Test Node or CTN) according to the DICOM standard. All these DNs were part of a Real World and could be inspected and operated.

The OSI model (2,3) which has served as the basis for both concept and design of the DICOM standard describes how heterogeneous systems could communicate. The necessary subfunctions of such a communication were defined as operations in seven layers. Implementation of this concept results in a "Real Open System" which according to the ISO document is sufficiently characterized by its behavior as an open system.

If we assume that the terminology of OSI can be applied to the world of the DICOM standard then we can define a **heterogeneous world** of medical diagnostic systems and a **homogeneous world** of communicating nodes on a DICOM network. Conformance to the standard is a prerequisite for such communication. The situation can be depicted as follows

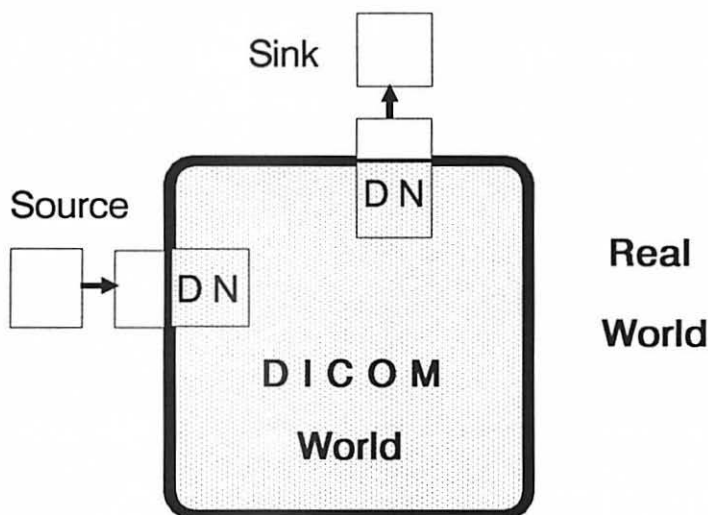


Fig 2 DNs bridge the Real World to the DICOM world.
They are implemented as Network Interface Units (NIUs) or gateways .

The DNs are physically "real" but bridge logically the heterogeneous world to the homogeneous world of DICOM. Such "bridging" implies both translation of "information objects" and conversion or encoding. For instance, original image data describing a round CT image must be converted to the DICOM format (i.e. a rectangular image).

The world of the RSNA demonstrations

The homogeneous world of the RSNA demonstrations bypassed the conversion of real world data and formats. Images and other information objects were pre-stored as conformant entities on the CTNs. Participating companies demonstrated that they could write, in a short time and on various platforms, software which produced DICOM conformant Protocol Data Units (PDUs). These PDUs are the building blocks for the DICOM network communication. The implementation of the DICOM communication protocol and typical PDUs by several vendors on various platforms was the "Real World" event. An " Open System" was thus established. This, by itself, was a significant accomplishment and an industry endorsement of the standard.

The next significant step, namely converting vendor specific image data according to the DICOM definitions and moving such normalized data into a DN equivalent equipment, is a vendor specific task. For that the DNs which were demonstrated at the RSNA exhibit can serve as prototype. In terms of "worlds" the vendor's modality as part of a heterogeneous world requires a vendor specific bridge into a homogeneous DICOM world as shown in Figure 2. Such step will, hopefully, be taken at the next RSNA exhibit and become another significant endorsement by industry.

The RSNA DICOM demonstrations included a Central Test Node (CTN) which has evolved from the concept of a common testsuite for various implementations of the DICOM standard. For operational reasons several (physical) CTNs cooperated as one logical CTN in order to improve the response. Obviously CTNs are not necessary for implementation of the standard and will play a less significant role in the next demonstrations.

The world of PACS

PACS (Picture Archiving and Communication System) or IMAC (Image Management and Communication) is a homogeneous world integrating heterogeneous systems such as modalities by various vendors. Its functions and services go beyond the scope of DICOM. For instance a PACS includes a Data Base Management (DBM) system which supplies not only convenient and robust access to information but also Structured Query Language (SQL) and generation of various reports and tables. DICOM defines information ("information objects" and "service classes") but does not perform information management in the more specific sense of a DBM.

PACS storage systems permit access to directories which contain attributes useful for simple searches. A system user should not be forced to enter detailed information for searches but should have the option of defining ranges (say of dates) and "wild cards" (i.e. undefined completion of entries) etc. DICOM does not offer such tools. The "FIND" command does not include a range of attribute values, although undefined attributes could be considered "wild cards".

PACS also includes image processing workstations. Such workstations provide useful services in the real world of radiology. Although the standard Application Entities (AEs) of DICOM do not include commands or service classes for such image processing, private AEs could be designed for such purposes.

The real world of Internet

Internet is an Open System according to the OSI definition. It permits access to information and resources to a large variety of heterogeneous systems. Internet E-mail communication was essential for an efficient coordination of the InfoRAD DICOM demonstration projects in 1992 and 1993. Internet is now offering downloading of the demonstration software developed by MIR and funded by RSNA. Furthermore "FinalDrafts" of the Dicom Standard are available on Internet.

DICOM 3.0 uses as one of the authorized communication "stacks" the TCP/IP transport protocol i.e. the same protocol that Internet is using. Therefore DICOM files as defined in part 10 of the standard could be sent

via Internet like any other files. The File Transfer Protocol (FTP) of Internet permits selection of files from various directories. Such directories are displayed on successful request for access via FTP. Without access to directory downloading of Internet file transport would be very cumbersome.

Internet has used originally exclusively strings of numbers for identification of addresses. But most users use now text strings organized by "domains" to access the system. These text strings were initially translated by "Network Information Centers" but are now translated by a "Domain Name System " into an equivalent string of numbers (4,5) . DICOM does not officially permit such replacement of the UID (string of up to 64 numbers) by text strings. It is conceivable, though, that every NIU in a PACS can convert UID name strings into UID number strings.

Since ARPANET served as model for Internet as well as for the OSI model it should not be surprising that DICOM and Internet can easily communicate with each other. As a matter of fact, Wide-Area-Networking (WAN) via Internet is fully compatible with DICOM.

The Global Real World

In a Global Real World as represented, for instance, by a radiology department within a hospital complex various heterogeneous systems exist next to each other. Human communication links them, translates and converts meaning and negotiates discrepancies if needed. DICOM is essentially a language for technical (diagnostic) communication. Like Esperanto it is an artificial language lacking historic resonances. The definition of "Service Classes" will be a compromise by classes of users and may not fit either one of them exactly. The homogeneous world of DICOM connects to heterogeneous worlds and systems via gateways or NIUs or DNs. There is no agreed upon good term for this important function. Commercial products exist which connect on one side to a specific modality and on the other side to a DICOM world, qualifying thus as NIUs. It is even likely that some companies will continue marketing their own diagnostic network, equipped, however, with a gateway to a DICOM network.

All this does not diminish the significance of the accomplishment. Much dedication and competence has been applied to the development of the DICOM standard. It was a wise decision to use the TCP/IP layers and to adopt the OSI terminology.

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 Part 2: Conformance
 Part 3: Information Object Definitions
 Part 4: Service Class Specifications
 Part 5: Data Structures and Encoding
 Part 6: Data Dictionary
 Part 7: Message Exchange
 Part 8: Network Communication Support for Msg Exchg.
 Part 9: Point-to-Point Communication Support for
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 Part 10: Media Storage and File Format
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Multivendor PACS: Stepwise Migration Towards DICOM

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I. INTRODUCTION

The introduction of a digital picture archiving and communication system (PACS) in a fully productive multivendor modality environment is a technical and organizational challenge^{1,2,3}. In order to bridge the gap between the former situation with non-interconnected image acquisition systems and the desired comprehensive PACS, the Zurich University Hospital follows a transition strategy with three steps: In a *first step* a standard inhouse image file format (Papyrus)⁴ and a transmission method (TCP/IP) were elected, and conversion routines were implemented for several modalities. The *second step* introduces DICOM⁵ objects into the existing TCP/IP and Papyrus environment by adding a communication module to the existing archive server. In *step three* DICOM communication modules will be introduced to every component in the image network, namely the Radiology information system (RIS) and the image display workstations.

Papyrus is based on the ACR-NEMA⁶ standard and can serve as a DICOM off-line data transfer and archiving file format. In our project, the Papyrus format has been chosen because of its close relationship with DICOM. A Papyrus file essentially encapsulates DICOM information objects. Therefore no information needed for DICOM gets lost by a Papyrus conversion. An archive consisting of Papyrus files can hence be integrated with emerging DICOM systems by means of a DICOM file service interface.

The ACR-NEMA DICOM (Digital Imaging and Communications in Medicine) standard allows the image object interchange among different computer systems over standard networks. The communication within DICOM systems is based on well-defined information objects, exchanged by use of specific protocols. Each system provides a set of standard operations relating to an information object class, and hence can be considered as a service provider. The archive type of services for instance allows storage, querying and retrieval of information objects without any restrictions to their internal representation.

II. METHODS AND MATERIALS

Since 1993, the Dept. for Medical Radiology of the Zurich University Hospital projects a comprehensive information system including a PACS and an RIS with image management capabilities. The RIS, a relational database application, has been successfully introduced in the beginning of 1994. The new systems have to deal with a considerably heterogeneous environment. They have to be networked with computer systems from different vendors, epochs, and operating systems. Eleven image acquisition modalities by four different vendors with divergent networking capabilities and image transfer protocols have to be integrated into the PACS (Fig. 3).

The currently introduced PACS is a first step towards an increasingly digital radiology department. Its primary goals are the archiving of all the Nuclear Medicine and PET images, the assessment of filmless reporting in Nuclear Medicine, and to provide the infra-structure for PET/MR/CT image fusion studies.

Basic principles of the projected system

- Keep it simple and open! The PACS should be an "open" and modular system built with *off-the-shelf* components. Modularity is achieved by exclusive use of standard interfaces for image communication.
- The PACS will account for the current standardization efforts. Specifically it will be able to incorporate systems conforming to the DICOM standard. Conversion from and reconversion to the proprietary image formats in the modalities are required.

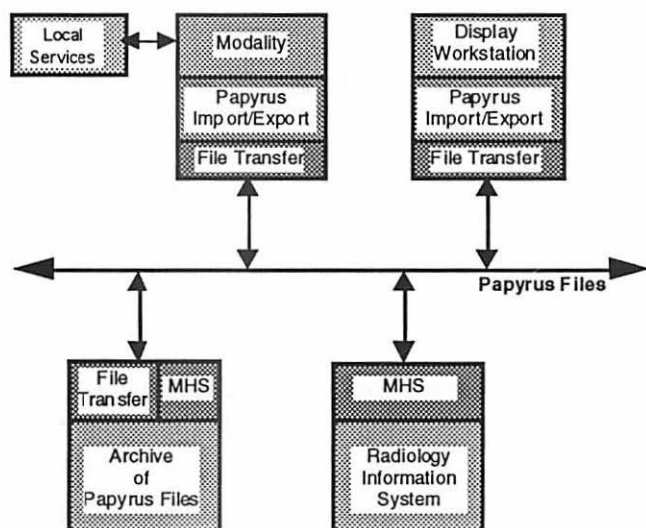


Fig. 1: Papyrus network. All image objects to be exchanged must be transformed into the elected standard inhouse format (Papyrus). These files are transferred using standard network facilities. At the destination, the Papyrus files are treated according to the intended purpose: They might be stored in an archive, their contents might be viewed on an analysis workstation or imported into a different modality. The RIS communicates with the archive subsystem by means of a message handling system (MHS).

- The specific environments of the modalities are not replaced. The system is designed to be a common platform for *simple* analysis and archival of radiological images.
- The installed RIS serves as the primary image management instance. This approach avoids unnecessary data redundancy and reduces the functionality and thus the complexity of the PACS archive service.

The PACS must integrate the modalities at a time before all the DICOM interfaces are available. It may even be possible that some modalities will never provide such an interface. As a consequence the solution scheme shown in Fig. 1 has been devised. Image movements are driven by the interfaced RIS, which also correlates patient, case, and examination information with image objects.

As a practical result of step one, images of five heterogeneous modalities can be combined for image fusion and stored in a central or a distributed archive, depending on organizational needs⁷ and the system capabilities. Fig. 3 represents the current state of implementation.

The second step is to integrate DICOM modalities. This is achieved by adding a communication module to the existing archive server (Fig. 2). We do not intend to develop DICOM interfaces for modalities.

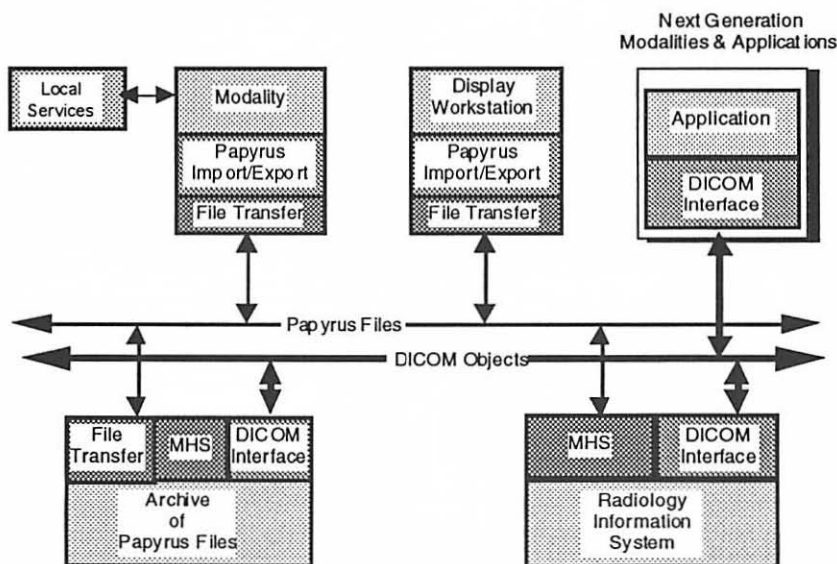


Fig. 2: Step 2, Integration of DICOM modalities. As Papyrus does comply with the DICOM specifications, emerging DICOM applications can be integrated in parallel to the existing conventional Papyrus file transfer network by introducing an interfacing file service software. It encapsulates/extracts DICOM information objects into/from files and communicates in a standard way with DICOM network nodes. The RIS provides the DICOM examination service for the new nodes in the network. The message handling system is still needed for managing the Papyrus file transfer.

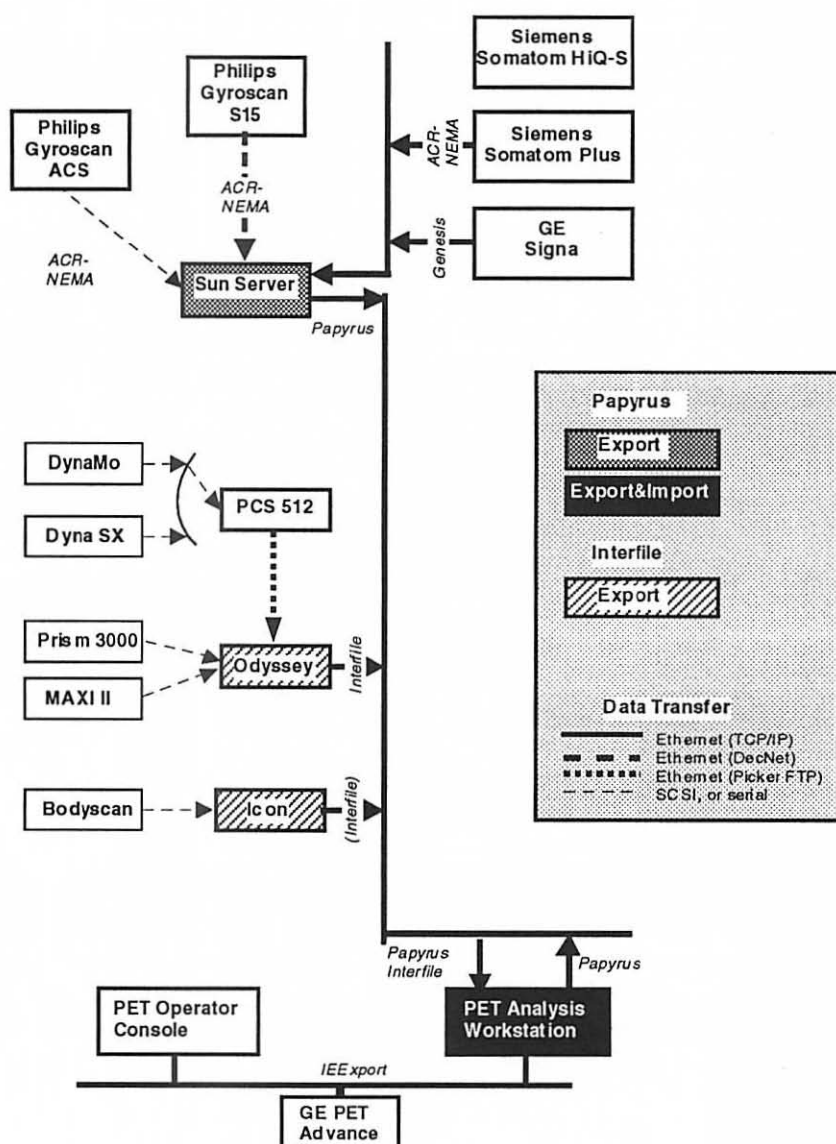


Fig 3: Currently implemented networking and conversion routines of the Zurich PACS project. Modalities situated in the Institutes of Diagnostic Radiology, Neuroradiology, and Nuclear Medicine are involved so far. Use of Papyrus as a departmentwide uniform image file format. Still missing, but urgently needed, is the Papyrus archive, and the interface to the RIS as the primary image management instance.

With the third step DICOM communication modules will be introduced to every component in the image network, namely the RIS and the image processing workstations (Fig. 4).

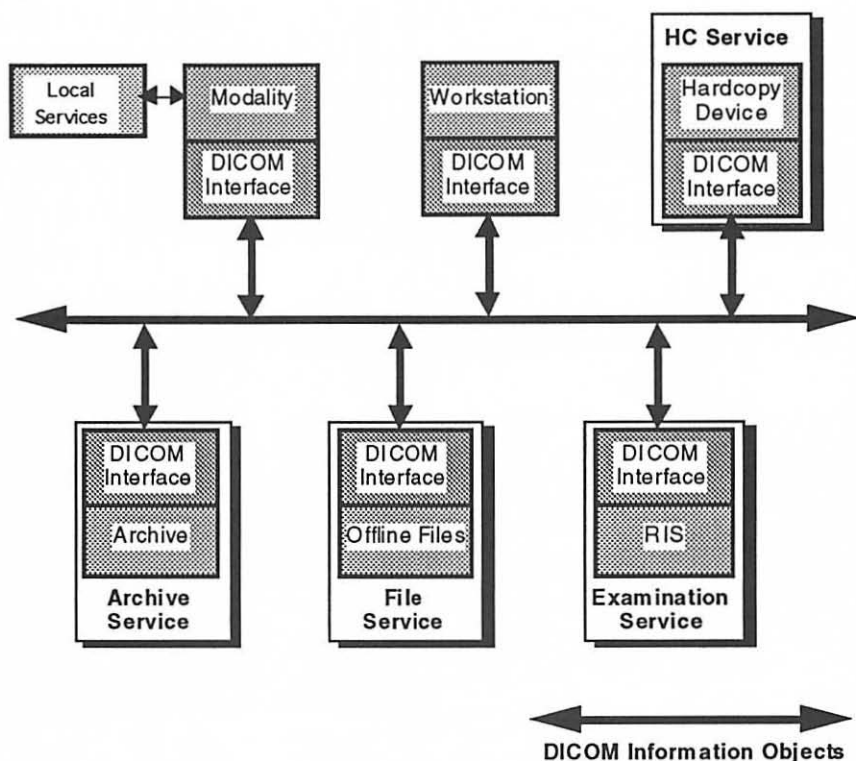


Fig. 4: Step 3. Plot of a "pure" DICOM installation. Ultimate goal of the stepwise migration policy.

III. DISCUSSION

A problem which must be considered when implementing Import/Export conversions is the potential loss of proprietary information. This is due to the fact that the standard's information model does not encompass every proprietary data attribute. Therefore primary image processing has to be done in the original (proprietary) modality environment. After the pre-processed image objects have been exported to the PACS environment, reporting is done by high quality viewing and *simple* image processing.

In *nuclear medicine* data exchange is increasingly often done using *Interfile* files. In the current version, Interfile's data model is quite different from DICOM and supports only nuclear medicine type of data. Modalities *within* the nuclear medicine department might well communicate via Interfile files as a temporary solution. How-

ever for image fusion, viewing and archiving in the described environment the Inter-file files have to be converted into the Papyrus file format.

The migration towards an all DICOM PACS seems to be manageable, though in a heterogeneous productive PACS environment the question of system security and the operational responsibility will remain crucial. A tight cooperation with the suppliers and a small but competent team of inhouse specialists will always be indispensable.

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Buying Imaging Products with a DICOM Interface— Made Easy

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I. INTRODUCTION

The ACR-NEMA DICOM Standard has been developed to facilitate the interconnection of medical imaging equipment in a multi-vendor environment. However, the DICOM Standard offers choices which need to be matched for imaging equipment to successfully communicate. For example, a CT scanner, sending CT images, will not communicate with a workstation which receives only MR images. For these reasons, the DICOM Conformance Statement was developed as a means for the purchaser of imaging equipment to assess whether devices will interoperate.

A DICOM Conformance Statement allows purchasers and vendors to determine which options are supported by a particular piece of equipment. By comparing the Conformance Statements from two different pieces of equipment a knowledgeable purchaser should be able to determine the features which will successfully communicate. Following the above example, a CT scanner, sending CT images, would be able to communicate with the workstation which receives both CT and MR images. This conclusion can be reached by reading the DICOM Conformance Statement.

The DICOM Standard requires that every product claiming conformance must have a Conformance Statement available which follows the framework established by Part 2 of the DICOM Standard. At first glance, a Conformance Statement may look quite imposing. As with any standard it includes unfamiliar terminology, such as Presentation Context, Abstract Syntaxes, SOP classes, Transfer Syntaxes, etc. However, with a few examples and minimum education these terms can become quite easy to understand. GE is committed to openly publish DICOM Conformance Statements for its products which include DICOM functionality.

This paper first provides a high level summary of the application features offered by DICOM. Secondly, it selects one of these features to illustrate that by reading two DICOM Conformance Statements, a purchaser is able to easily determine whether

two devices can successfully communicate. This can be achieved without in-depth knowledge of the DICOM Standard itself. Although the two examples used are a GE CT HiSpeed Advantage RP scanner and a GE Advantage Windows workstation, this analysis process may be generalized for any two DICOM products.

II. SUMMARY OF DICOM APPLICATION FEATURES

There are currently four key application features specified by DICOM. These include:

- Network Image Transfer
- On-line Imaging Study Management
- Network Print Management
- Open Media Interchange

Network Image Transfer provides the capability for two devices to communicate by sending images, querying remote devices, and retrieving images. This is commonly performed between scanners, workstations, archives, etc.

On-line Imaging Study Management provides imaging devices the network capability to manage study, patient, and results information (often called a HIS/RIS Interface). Some examples are informing a scanner that a study has been scheduled, downloading patient demographic information to the scanner, uploading study completed information to an image manager, and retrieval of reports.

Network Print Management provides the capability to print images on a networked camera. An example is multiple scanners or workstations printing images on a single shared camera.

Open Media Interchange provides the capability to manually exchange images and related information (e.g., reports or filming information, etc.). DICOM standardizes a common file format, a medical directory, and selects a standard physical media. Some examples are the exchange of images for a publication or mailing a patient imaging study for remote consultation.

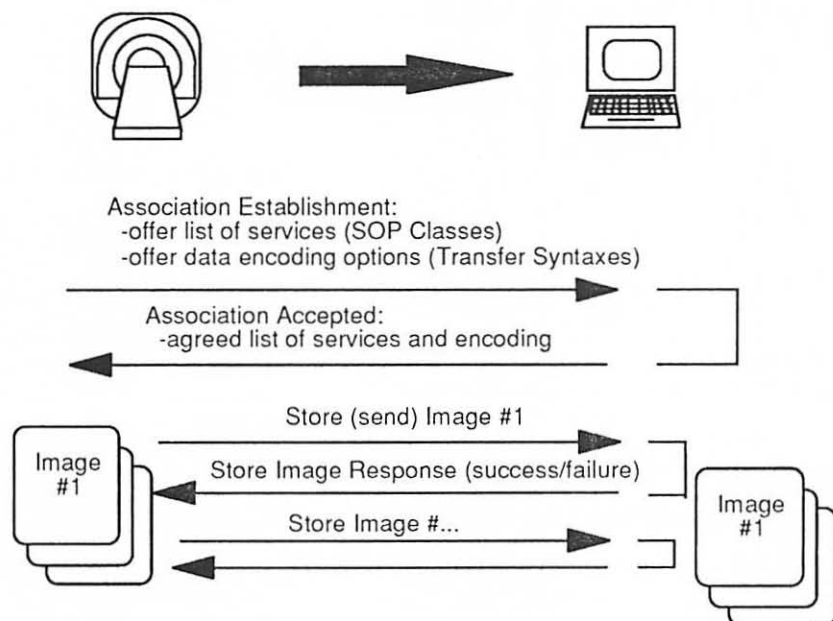
Because Image Network Transfer is currently the predominant connectivity feature, it will be used as the example to demonstrate the ease of reading DICOM Conformance Statements.

III. EXAMPLE OF IMAGE NETWORK TRANSFER

Network Image Transfer provides the capability to send images, query remote devices, and retrieve images. For two devices to achieve connectivity they must

support complementary networking roles, user and provider. Figure 1 illustrates these respective roles of a scanner pushing images to a workstation.

Pushing DICOM Images



**Figure 1: The Storage Service Class:
Principle of Operation**

The ability to send images in DICOM is accomplished using the Storage Service Class. The sender (or Storage Service Class User) is the scanner, and the receiver (or Storage Service Class Provider) is the workstation. The scanner must first establish an "association" with the workstation. This handshake is used to negotiate a common set of services. The content of the offer (made by the scanner in Figure 1) is called a Proposed Presentation Context. The response (made by the workstation) is called the Accepted Presentation Context. Assuming that the Storage Service Class has been agreed to, the scanner is now able to send images to the workstation.

The same two step approach is shown in Figure 2. In this example the Query/Retrieve and Storage Service Classes have been negotiated, thus providing the ability for the workstation to "pull" images from the scanner.

Pulling DICOM Images

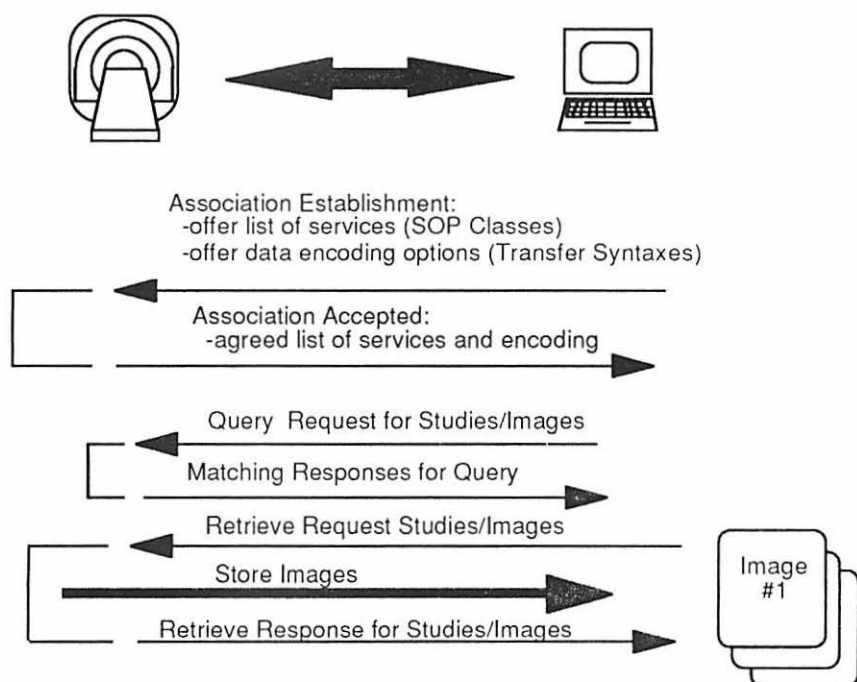


Figure 2: The Query/Retrieve Service Class including the Storage Service Class

Two key concepts which form the heart of the DICOM Conformance Statement are:

- 1.) The concept of role for each network Service Class supported (Service Class User, Service Class Provider, or both).
- 2.) The concept of Presentation Context which includes the list of elementary services (called Service Object Pair (SOP) Classes) that are offered or accepted.

IV. DICOM CONFORMANCE STATEMENT

To evaluate the connectivity between two devices their Conformance Statements must be compared. The Conformance Statements contain many technical details, very important for installation, implementation, etc. The vital information to determine connectivity is contained in two tables, a Proposed Presentation Context

list and an Accepted Presentation Context list. Sections from two actual DICOM Conformance Statements (GE CT HiSpeed Advantage RP scanner and a GE Advantage Windows workstation) are used to illustrate the evaluation of the Image Network Transfer feature.

The GE CT HiSpeed Advantage RP DICOM Conformance Statement Presentation Context Tables are shown in Tables 1 and 2:

Table 1:

Table 2.2.1.2.1.2 Scanner Proposed Presentation Contexts

Presentation Context Table					
Abstract Syntax		Transfer Syntax		Role	Ext. Negot.
Name	UID	Name List	UID List		
CT Image Storage SOP Class	1.2.840.10008.5.1.4.1.1.2	Little Endian	1.2.840.10008.1.2	SCU	None
Secondary Capture SOP Class	1.2.840.10008.5.1.4.1.1.7	Little Endian	1.2.840.10008.1.2	SCU	None
Standalone Overlay SOP Class	1.2.840.10008.5.1.4.1.1.8	Little Endian	1.2.840.10008.1.2	SCU	None

Table 2:

Table 2.2.1.3.1.2 Scanner Accepted Presentation Contexts

Presentation Context Table					
Abstract Syntax		Transfer Syntax		Role	Ext. Negot.
Name	UID	Name List	UID List		
Verification SOP Class	1.2.840.10008.1.1	Little Endian	1.2.840.10008.1.2	SCP	None
Study Root Query / Retrieve Info. Model - FIND SOP Class	1.2.840.10008.5.1.4.1.2.2.1	Little Endian	1.2.840.10008.1.2	SCP	None
Study Root Query / Retrieve Info. Model - MOVE SOP Class	1.2.840.10008.5.1.4.1.2.2.2	Little Endian	1.2.840.10008.1.2	SCP	None

The GE Advantage Windows workstation DICOM Conformance Statement Presentation Context tables are shown in Tables 3 and 4:

Table 3:

Table 2.2.1.2.1.2 Workstation Proposed Presentation Contexts

Presentation Context Table					
Abstract Syntax		Transfer Syntax		Role	Ext. Negot.
Name	UID	Name List	UID List		
CT Image Storage SOP Class	1.2.840.10008.5.1.4.1.1.2	Little Endian	1.2.840.10008.1.2	SCU	None
MR Image Storage SOP Class	1.2.840.10008.5.1.4.1.1.4	Little Endian	1.2.840.10008.1.2	SCU	None
Secondary Capture SOP Class	1.2.840.10008.5.1.4.1.1.7	Little Endian	1.2.840.10008.1.2	SCU	None
Study Root Query / Retrieve Info. Model - FIND SOP Class	1.2.840.10008.5.1.4.1.2.2.1	Little Endian	1.2.840.10008.1.2	SCU	None
Study Root Query / Retrieve Info. Model - MOVE SOP Class	1.2.840.10008.5.1.4.1.2.2.2	Little Endian	1.2.840.10008.1.2	SCU	None

Table 4:

Table 2.2.1.3.1.2 Workstation Accepted Presentation Contexts

Presentation Context Table					
Abstract Syntax		Transfer Syntax		Role	Ext. Negot.
Name	UID	Name List	UID List		
Verification SOP Class	1.2.840.10008.1.1	Little Endian	1.2.840.10008.1.2	SCP	None
CT Image Storage SOP Class	1.2.840.10008.5.1.4.1.1.2	Little Endian	1.2.840.10008.1.2	SCP	None
MR Image Storage SOP Class	1.2.840.10008.5.1.4.1.1.4	Little Endian	1.2.840.10008.1.2	SCP	None
Secondary Capture SOP Class	1.2.840.10008.5.1.4.1.1.7	Little Endian	1.2.840.10008.1.2	SCP	None
Standalone Overlay SOP Class	1.2.840.10008.5.1.4.1.1.8	Little Endian	1.2.840.10008.1.2	SCP	None

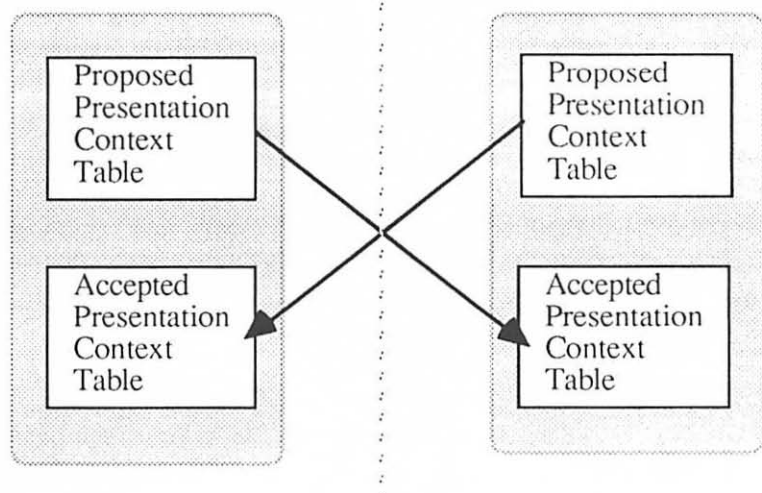
Following is an explanation of the terms used in the above tables:

- Presentation Context Table - The name of the table which conveys the list of features (proposed and accepted) offered by a product.
- Abstract Syntax - The identification of the actual elementary DICOM feature, called a SOP Class (e.g. CT Image Storage).
- Transfer Syntax - The identification of the data encoding (all devices are required to support the DICOM default of Little Endian). There may be multiple Transfer Syntaxes for each Abstract Syntax.
- Role - The identification of the service role, user and/or provider, called a Service Class User (SCU) and Service Class Provider (SCP).
- Extended Negotiation - All features support a default level of connectivity, this field allows for optional extensions to each feature, beyond the default.
- UID - A globally unique number used to identify key parameters.

Figure 3 shows how the complementary Presentation Context tables are compared from the two Conformance Statements:

GE CT HiSpeed Advantage RP -
DICOM Conformance Statement

GE Advantage Windows -
DICOM Conformance Statement



The two key parameters to compare are the Abstract Syntax of the Presentation Context Item and the Role (Service Class). For the Abstract Syntax, the Name value is informative only, the key is to compare the UIDs. Upon matching these UIDs, the next crucial step is to compare the Roles for that Abstract Syntax. The Roles must be complementary (e.g. an SCU will not communicate with another SCU). The

Transfer Syntax is not important for connectivity (since all products must support the default Little Endian), however it can be used for optimization (e.g. JPEG compression). Extended Negotiation is similar to the Transfer Syntax in that a default is always defined for each Abstract Syntax.

We can now evaluate the connectivity scenario in Figure 1 to compare the GE CT HiSpeed Advantage RP scanner (SCU) sending images to the GE Advantage Window workstation (SCP). By comparing the Abstract Syntax UIDs and Roles in Table 1 and Table 4 it can be easily determined that the scanner is able to send CT and Secondary Capture images and Standalone Overlay information to the workstation. The workstation is also able to support MR images, but this feature will be not be used when communicating between this scanner and workstation.

Evaluating the connectivity scenario in Figure 2 (query and retrieval of images) can also be simply determined. By comparing the Abstract Syntax UIDs and Roles in Table 3 and Table 2 the workstation is able to query the scanner for database information (e.g. List Select) and also retrieve images.

V. Summary

The DICOM Conformance Statement was developed as a means for purchasers and vendors of imaging equipment to assess whether products will interoperate. Any product which claims DICOM conformance is required to publish a Conformance Statement.

By understanding a few key terms and comparing two Conformance Statements a purchaser can easily determine whether basic connectivity is achievable.

A Multimedia Multipoint Communication System for Medical Consultations

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I. INTRODUCTION

In the past few years, the emerging new technology of communication networks and protocols has resulted in the development of distributed communication systems, which are used mainly for sharing and manipulation of multimedia information among users distributed geographically. One of the most important applications which have been developed recently, is the medical consultation systems. These systems have been designed in order to provide remote medical services (e.g. diagnosis, training) to distant sites and Medical Health Centers.

Early implementation of such systems are the IRIS system developed in Ottawa¹, the NMIS in Boston², and the MICA project B-ISDN field trial developed in North Carolina³.

In this paper we present a MULTImedia MULTipoint COMMunication System for medical consultations (MUMUCOS) which satisfy the characteristics and requirements of the medical environment. The system provides:

- a) the capturing of medical images directly from various medical modalities.
- b) the creation and manipulation of medical multimedia databases which will contain all the patient information (patient data, laboratory findings, medical images, past diagnoses, e.t.c.).
- c) a full-duplex multipoint communication service among an arbitrary number of users located on geographically distributed sites and interconnected by a variety of networks (such as widely connected LANs, X.25, ISDN).
- d) the image processing, compression tools for the best manipulation of medical images.
- e) a friendly Graphical User Interface designed specifically for consultation purposes.

This paper is composed of four sections. In Section II the system architecture, thus the medical and communication requirements imposed on the system and the functions developed to accommodate these requirements, are described. In Section III the prototype implementation of the system architecture is presented. Finally some conclusions and plans for future work are given.

II. SYSTEM ARCHITECTURE

MUMUCOS supports its users with the ability to engage in consultation at a distance and have simultaneous viewing and manipulation of shared medical information. The information generated in a medical environment is consisted of multiple types⁴, such as patient data (name, address, blood type e.t.c.), imaging data (modalities, image characteristics, patient orientation e.t.c.), expert annotations (text, voice, graphics) that accompany the imaging data. The above description serves to point out the multimedia nature of medical information.

In Figure 1, the structural model of the system is presented. It is consisted of a Graphical User Interface (GUI), a Multipoint Communication Agent (MCA), a Medical Data Management Agent (MDMA) which consists of two modules: a DataBase Manager (DBM) for the interaction with the database and an Image Processing Tool Library (IPTL). The system is managed through a Management Entity (ME) which is used for system debugging, error logging and other control functions. Media devices other than standard I/O devices (screen, pointing devices) are supported by a Media Devices Entity (MDE) which interacts with the GUI or directly with the MCA.

A. Graphical User Interface (GUI)

The GUI is specifically designed to accomodate the conferencing needs of the system users. The main characteristic of a conferencing user interface is the shared space for medical data (image, text) representation. Users can access and modify data presented in the shared space. The modifications are simultaneously viewed by all participants, in order to fulfill the WISIWYS (What I See Is What You See) principle. A private working space is available where each user can process his own information. All the necessary commands for the summoning and releasing of a conference are included in the Control Panel. The feedback of these commands are displayed in the Status Panel. The Media Device Control Panel includes all the necessary commands for the manipulation of the conference media. The user interacts with the system through the GUI. The user commands are interpreted by the GUI to primitives which are sent to various Agents and Entities.

B. Media Device Entity

This module includes all the media drivers required for the capturing and displaying of the various media information (loudspeakers, microphones, video cameras). Moreover, this entity supports low bit-rate coding techniques for bit rate reduction purposes, filtering techniques (e.g. silence detection for voice filtering).

C. Multipoint Communications Agent (MCA)

Conventional networks support point-to-point communications for a given service. Conferencing systems however require multipoint connections among end-users for the distribution of multimedia information. The MCA provides services for

conference control and conference data distribution among the multipoint sites. In Figure 2 we present the association between the end-users, MCA and the communication network. In this paper the term call is used to describe a logical association between an arbitrary number of end-users exchanging multimedia objects. The term connection is used to describe the logical association between an arbitrary number of end-users for a given service. The term channel is used to describe a point-to-point connection. The MCA resides either at the user equipment or at the network nodes equipment. In the second case, only the Connection Manager is required, the network node acts as a distributed bridge to provide services to the attached users.

The MCA is consisted of two managers (Fig. 1):

- a) The *Call Manager* dealing with the conference as a whole, making the semantics and syntactic analysis of the user messages, keeping information about various media supported by the conference and media devices access points and finally is responsible for protocol function processing and
- b) The *Connection Manager* which is responsible for the connection establishment, data tranfering between communication channels and media devices, and multicasting operations.

The MCA provides a set of service functions for the conference support. These include opening and closing the conference, members' joining and leaving, floor passing, etc. These functions are provided to the conference participants through the MCA protocol. The conference convener sends a conference set-up primitive to the MCA. The primitive includes the convernre, a list of participants to join the conference, a list of media to be used during the conference, the logical topology of users sites (e.g. users that are accessed through a bridge should be known to the MCA as well as the bridge's address) and the conference rules (e.g. floor holder modes, simultaneous opening of various media devices, essential users and media). The MCA Call Manager checks this primitive for semantic errors, analyzes the call requirements and generates the appropriate primitives to the MCA Connection Manager to create a *basic* connection (logical path) among the end-users, to be used for the exchange of control information. the MCA Connection Manager establishes a channel with each user. Each channel is controlled by an appropriate I/O Handler. Each I/O Handler is network specific, i.e. network-dependent software is used for the implementation of I/O Handlers. Every user responds with a positive or negative acknowledge message. Each user's acknowledge message includes a list of the supported media to be used during the conference. The Connection Manager creates a list of binded participants and supported media by each participant, and returns it to the Call Manager. If some of the essential users cannot participate in the conference or some of the essential media cannot be supported, the conference is terminated. After the basic connection is established, the MCA Call Manager creates a connection for every medium (voice, video) denoted on the initial call setup primitive (the user can add additional media during the conference). During the conference, data are exchanged through corresponding connections (one connection per medium). The Call Manager is aware of the endpoints of each media device, which are the known to the Connection Manager within each media setup primitive. Therefore, samples of each medium are routed to the corresponding

channel. In the destination, samples from each channel are routed to the corresponding media device.

The convener is the first floor holder. The floor holder right can be passed to the other participants according to the rules described in the Conference SetUp user primitive. There are four modes for the passing of the floor holder right⁵.

Each user can join an ongoing conference and also can leave a conference before it ends. The conference ends only when the floor holder issues a Call-Terminate message, or after the last of essential participants leaves the conference.

Multipoint flow control is performed within the MCA Connection Manager for each individual connection. This results in the limitation of the connection data flow to the speed of the slowest channel. Synchronization functions of the exchanged multimedia objects are also provided among end-users by means of the MCA protocol.

D. Medical Data Management Agent (MDMA)

The MDMA takes control of the multimedia medical information manipulation and presentation. It consists of two modules: a Database Manager (DBM) for the interaction with the medical Database and an Image Processing Tool Library (IPTL).

The DBM is responsible for archiving and reducing the exchanged data during the conference in order to minimize the response time of the system. This is achieved by:

- a) archiving each image in two types, original and token (compressed).
- b) applying the appropriate compression technique from the Image Compression Library on the image data, respectively to the image characteristics⁶ and
- c) using short commands - messages to activate image processing in remote stations.

Also, the DBM has the ability to convert all the patient information data and the corresponding images to/from ACR-NEMA or POPYROUS file formats stored in the Database⁷.

The IPTL contains operators and tools. The operators are basic image processing algorithms activated by the tools which are divided in groups corresponding to the human organs and contain elements corresponding to the modalities. The image processing operators have been associated in different groups depending to their functionality, such as contrast modifications, statistical information, spatial transformations, algebraic, logical, edge detection, ROIs, segmentation and filtering operations. Most of these operators have been developed by the RACE-TELEMED project⁸. Each operator can be called by several tools and each tool can be called by more than one modality, since some human organs are examined by various modalities (e.g. lungs can be examined using the Gamma Ray camera, CT and X-Ray). The IPTL offers powerful features for medical image processing and analysis application, thus providing the physicians with a means of analyzing and estimating medical images in order to accomplish their diagnostic procedures.

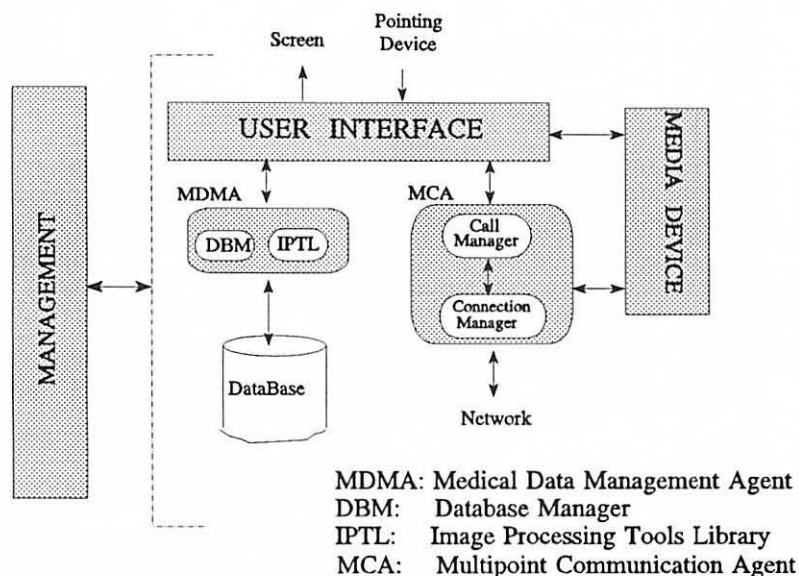


Figure 1: System Architecture

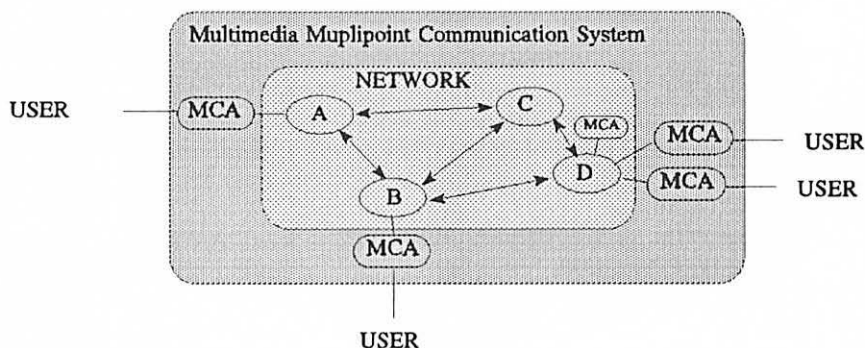


Figure 2: Association between users, MCA and network

E. Management Entity

This entity manages the conference. It keeps the conference history (list of participants, list of media, subject, duration, convener, e.t.c). Moreover it is used for conference control and debugging. An errorlog is used to register all the errors (network and application) that occurred during the conference. An other operation is using the entity as an electronic organizer, making appointments and scheduling the

next conference to take place. Finally, this entity is used for call redirection whenever a participant has moved to another site.

III. SYSTEM IMPLEMENTATION

A prototype system has been implemented in the Wire Communications Laboratory of the University of Patras, using Sun SPARCstations. A conference was held among an arbitrary number of participants, residing at the WCL and at the Regional University Hospital of Patras. Medical personnel were able to summon conferences, to create, view and manipulate medical multimedia documents, and to participate in remote diagnostical procedures^{9,10}. Some of the stations were used as medical workstations while others stations were used as network bridges. This prototype system has been tested under real conditions.

IV. CONCLUSIONS

This paper presents a new system for multimedia multipoint communications for medical consultations. This system provides its users with the ability to engage in a conference and supports functions for image handling, voice handling, telewriting and telepointing. It has been implemented in the WCL of the University of Patras and has been tested under real conditions. Future work includes the design and implementation of this system under broadband networks.

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Migrating a Network Towards a Switched Ethernet Over an ATM Backbone

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Introduction

Traditionally, large Ethernet networks have been composed of several segments interconnected through bridges and routers. Bridges are used for isolation and a router is used to connect the individual LANs. This is commonly referred to as a segmented collapsed backbone network. While probably the most popular network layout, it suffers from many drawbacks in today's bandwidth hungry environment.

Medical imaging applications are very demanding of network bandwidth and throughput. An Asynchronous Transfer Mode (ATM) local area network has been installed to satisfy this demand and to provide a foundation for an imaging network. Direct ATM connections operating at 155 Mbps will be used for primary image transmission in radiology and as a vehicle for transmission of video and voice. Our initial tests of commercially available ATM switches have allowed us to transfer image data without network limitations.

To provide for future network growth and scalability on our present Ethernet, we are migrating from the present segmented collapsed backbone to a switched Ethernet over an ATM backbone. Ethernet switches isolate connections into private CSMA/CD segments similar in function to a bridge, but with much less latency. ATM will provide the high speed connection between the switching engines. A router will still be used to complement the network and provide a path to the existing wide area network.

This topology is very cost effective since it does not require new network cabling or network adapters for Ethernet and still provides for increased usable bandwidth in a scalable architecture. By providing a very high speed path between the Ethernet switches, we will be able to support virtual LANs. This will allow allocation of private Ethernet segments between hubs thus providing physically disparate users and workstations more bandwidth and dramatically reduced latency.

The Digital Imaging Network

One of the primary reasons for installing the ATM network is as the backbone for the radiology imaging network. Currently, Ethernet does not provide sufficient

bandwidth for clinical applications involving the transmission of radiological images. FDDI is a marked improvement, providing much higher bandwidth but still as a shared media. In a model of a large clinical Picture Archival and Communications System (PACS), ATM appears to be better equipped to handle our image transmission needs. The emergence of ATM in the broadband area, most notably the Information Highway, should pave the future for ATM in Telemedicine.

The Department of Radiology at Duke University Medical Center installed three SONET based ATM switches in January of 1994 as the first step towards our main imaging network¹. One switch was installed in our North Hospital, one in our South Hospital, and the third in the radiology research area. The switches are connected via multi-mode fiber Network Node Interfaces (NNI) operating at 155 Mbps. More NNI links will be installed as traffic patterns dictate.

A major advantage of the circuit-based ATM network over the shared-media network is that traffic between two computers travels over a defined circuit as opposed to being transmitted over a shared media (i.e., Ethernet). Direct ATM connections will be used for high performance imaging applications and will provide dedicated bandwidth for the workstation or server. This will prevent imaging traffic from congesting the Ethernet network and will also isolate imaging traffic from other ATM workstations.

The imaging network will consist of both ATM and Ethernet. Ethernet will be used mainly in the transmission of images from acquisition devices to storage devices. ATM will be used for transmission of images from storage to display or wherever performance is critical. It is important that ATM and Ethernet operate as one homogenous network so that we preserve our current Ethernet connectivity but still satisfy applications which demand ATM speeds.

ATM Connections (PVCs and SVCs)

There are currently two methods of establishing an ATM connection, Permanent Virtual Circuits (PVC) and Switch Virtual Circuits (SVC). PVCs are permanent and must be manually constructed and removed. The standards on PVCs have been well adopted and should provide current interoperability between different ATM manufacturers (provided the rates are the same). SVCs are established on a need basis (much like making a phone call). The standards on SVCs are not as well defined as PVCs. As such, interoperability with SVCs probably will not happen until later in this year (or even next year). Our switch manufacturer currently provides SVC support on their product line. Anyone interested in purchasing ATM equipment today should familiarize themselves with the implications of SVC interoperability.

IP Over ATM

¹These are the Synoptics LattisCell ATM Switches

There are several issues that arise when running IP over ATM. These issues arise due to the difference in addressing in ATM and in the circuit-based connections. The transmission of IP datagrams using ATM cells is fairly straightforward using a common segmentation and reassembly (SAR) method. Address resolution in an ATM IP environment is slightly more complex. Classical address resolution (ARP) on an Ethernet network utilizes a special broadcast packet that asks for the IP to MAC level address translation. In a non-broadcast, non-multicast environment, broadcasts will not occur. "Classical IP and ARP over ATM" [2] requires a single ATM based server for resolving the ATMARP request (directed ARP). Clients on the ATM network must be configured with the ATM address of the ATMARP Server. Clients will connect to the ATMARP Server using a point-to-point virtual connection. It is reasonable to assume that the current ATMARP scheme should evolve over time from this approach to a more robust approach.

Routing IP in an ATM network also presents some current challenges. As currently defined in [2], ATM IP subnets are connected via an ATM router. This router should support multiple Logical IP Subnets (LIS) and should provide all the routing with a single physical ATM interface. The interested reader is directed to [2] for a more detailed analysis of routing in an ATM environment.

TCP/IP Performance over ATM

The performance of TCP/IP over ATM is of great interest. Even though TCP/IP is not the most efficient protocol for ATM, it will probably be the most widely used. Our tests of TCP/IP over ATM yielded some very satisfactory results with a few small surprises.

Our test suite consisted of three ATM switches and three Sparc 10 51s (uniprocessor). One of these Sparc 10s is connected to the Ethernet Port on one of the switches. This Sparcstation downloads configuration information to the switches and controls the signaling (including SVCs) in the ATM network. The other two Sparc 10s have direct ATM connections to the switches.² All the interfaces are running at the OC3C rate of 155 Mbps. One of the latter Sparcstations also has an Ethernet adapter and is operating as a router to provide connectivity between our ATM and Ethernet networks. This will be replaced in the future by an Ethernet switch which has Ethernet and ATM connections.³

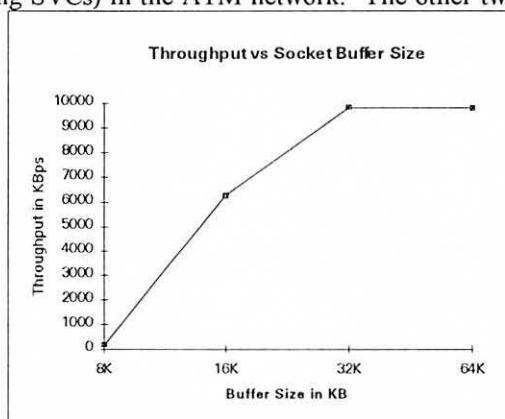


Figure 1

²The Sparcstations are equipped with Synoptics SBUS ATM Host Interface (SAHI) adapters

³The Ethernet-to-ATM switch is a Synoptics EtherCell

As discussed in [3], the performance of TCP depends upon the product of the transfer rate and the round-trip delay. As this product increases, the buffer space required must also increase. This became readily apparent during our initial tests that showed TCP/IP performance in the 200-300 KBps range.

For high performance throughput, it is necessary to properly tune the buffer sizes at the end workstations. A graph of buffer size versus throughput is shown in Fig 1. Our highest throughput measurements were in the 10 MBps (80 Mbps) range and were very consistent. The tests were performed using the publicly available test tool *ttcp* as well as some of our own in-house tools. Both tools produced similar results.

Interestingly enough, the limitation on throughput was not the ATM network. The same tests run on only one machine (i.e., loopback tests) produced similar results (actually, the loopback performance was worse, probably due to two processes running on the same machine). At the time the tests were run, both performance meters showed CPU utilization at 100%. This data implies that the limiting factor on throughput was the two end workstations and not the ATM link. We do not conclude that this is the limit on the throughput of these workstations. With some more work on enhanced drivers and proper kernel tuning, these numbers should increase.

We were able to attain rates of 10 MBps using standard hardware and unmodified operating systems with our test programs which transmitted test data from one machine to another. When these programs were modified slightly to transfer images, a significant performance impact was noticed. Our original test programs (on the receiving end), read the packets into the same memory location. When a modification was made so that packets were read into sequential memory locations (as an image would exist in memory), performance degraded to 5 MBps. Obviously, in this case, the limiting factors are the workstations. Once again, we do not conclude that this is the limit on these workstations. Proper tuning of the operating systems should yield better results.

FTP and RCP performance were surprising at an average of 300 KBps. However, when we tested FTP and RCP from a ramdisk to a ramdisk (/tmp may be used on Solaris with tmpfs), performance averaged 4 MBps. It is clear that proper tuning (or possibly OS patches) will be necessary to attain high throughput rates.

Our initial tests of TCP/IP traffic over ATM at the OC3C rates (155 Mbps) were very promising. While we achieved some high throughput numbers, it was clear that the two endpoint computers were the influencing factors in the throughput performance. The ATM switches were able to transmit data as fast as the computers could place data onto the network. It has become obvious to us that increased TCP/IP performance over ATM will be accomplished by faster processors, enhanced drivers (i.e., multi-threaded), TCP/IP stack optimizations, and correct tuning of the operating systems.

business users from imaging users. The high speed backbone is necessary to support the creation of Ethernet segments that span across switches. A router will still be used to connect to the campus and wide area networks. A high level view of this architecture is depicted in Figure 2. This drawing is intended to depict the separate Ethernet segments.

Performance Advantages of the Switched Network

Although a debatable topic, most network managers will agree that Ethernet performance generally suffers when the percentage utilization approaches 30%. Although our current Radiology Ethernet does not suffer from this high percentage utilization yet, we have noticed a marked increase recently, and most notable, some very high peak rates (above 90%). These peak rates have been occurring more frequently as higher performance workstations are added to the network and as the transfer of radiological images becomes more prevalent.

Our new switched network will provide separate Ethernet segments so that traffic on one segment does not interfere with traffic on another segment (although we will have only one broadcast domain). This is logically similar to segregating a network utilizing bridges, however, the switched Ethernet approach allows us to centrally manage the segments. Segments may also span across the ATM switches. This allows us to place two users on the same segment even if they are physically separated by a long distance.

Our current investment in Ethernet adapters is secure and the performance of the Ethernet network should remain adequate which makes this architecture very cost effective. Our investment in cabling is also spared since the switching engines are located in the wiring closets with the Ethernet hubs. Workstations that require increased bandwidth including file servers and imaging workstations will have dedicated OC3C (155 Mbps) ATM connections.

Conclusion

We have begun the migration from our segmented collapsed backbone to a switched Ethernet over ATM. The network design presented here should provide enough bandwidth and scalability to meet our future needs as well as provide the transfer rate necessary for medical imaging applications. In addition, high bandwidth connections to remote facilities should prove feasible as the wide area providers offer ATM connections. Our initial tests of the ATM switches showed that high throughput is achievable using TCP/IP. Proper tuning of the end workstations will be a major factor in achieving this throughput.

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Real-time Fluoroscopy and Ultrasound

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ABSTRACT: Radiology applications involving isochronous bandwidth and high speed asynchronous connections have been frustrated by the lack of standards-based implementations. With the emergence of Asynchronous Transmission Mode (ATM), fiber distributed data interface (FDDI, ANSI X3.139), and switched IEEE 802.X Local Area Networks (LANS), many of these applications are now becoming possible. For example, one aspect of costly sub-system in digital radiology is the disk sub-systems. If a network is deployed that has a bandwidth that exceeds the backplane bandwidth of a workstation, possibilities exist for greatly reducing diagnostic workstation costs by distributing the costs of a single, high-performance, disk sub-system over diskless, networked workstations. Furthermore, if a network can provide between and 36 to 126 Megabits per second (Mbps) of isochronous bandwidth, real time fluoroscopy and ultrasound become possible. North Carolina is installing a state-wide ATM network that will deliver OC-3c to 3700 sites. One group of recipients is the hospitals throughout the state. With proper workstation choices and high-performance ATM interface cards, real-time fluoroscopy and ultrasound should be possible with off-the-shelf equipment.

I. INTRODUCTION

With the development of the National Information Infrastructure (NII), many states have launched programs to provide some degree of ATM service. The state of North Carolina aggressively seeks to provide equal access across the state to its ATM service supplying OC-3c connections (155 Mbps) to 3700 sites.^[1] Initially, nine ATM switches provide connections to 105 sites^{[2][3]} that include 11 hospitals. This promises to provide high bandwidth to North Carolina users at costs far less than today's DS3 (45 Mbps) costs.

For digital radiology to become economically feasible, the network bandwidth and the workstation I/O bandwidth had to significantly increase. For instance, real-time digital ultrasound was predicted when high-performance network and computer technologies became standardized and cost-effective.^[4] These technologies are available and real-time digital ultrasound is now possible. The similarity of the digital streams of digital fluoroscopy and ultrasound makes digital

fluoroscopy possible.

Real-time ultrasound involved using either specialized analog connections^[5] or attempting analysis with a lossy compression scheme. In the past, fluoroscopy generally remained analog. Full-motion digital ultrasound usually involved a costly disk subsystem, a proprietary data network, and a computer operations specialist to handle the media and place studies on the appropriate file system or raw I/O device.

The remainder of the paper deals with the computer protocols, workstations, and the modality inputs used to implement real-time, digital tele-ultrasound and tele-fluoroscopy systems.

II. COMPUTER PROTOCOLS

Campus area network backbones are being implemented with high-performance networks using FDDI and ATM technology. High-data-rate hubs are putting new life into the legacy LANS. These hubs support IEEE 802.3 (CSMA/CD or ethernet) and IEEE 802.5 (Token Ring) sometimes in a switched environment such that a workstation essentially obtains the entire bandwidth of the legacy LAN. Some hubs even support switched FDDI protocols. So bandwidths at or exceeding 100 Mbps are now available to a workstation at reasonable prices. Of these, ATM technology is most interesting as it was designed to handle constant bit rate applications such as real-time voice and video, as well as data applications at bandwidths up to OC-48 (2.54 Gigabits per second (Gbps)) although there are no inexpensive workstation interface cards operating OC-48 data rates. It also allows isochronous bandwidth to be guaranteed for full-motion video for the ultrasound and fluoroscopy. Teleconferencing, in general, is more tolerant of latency fluctuations, however, isochronous bandwidth is important to tele-ultrasound and tele-fluoroscopy as all frames and their temporal sequence must be maintained for proper diagnosis.

This only addresses the data link layer protocols. At the transport layer (an end-to-end protocol), packet-video protocols are still evolving. Of the emerging packet-video protocols, The Xpress Transfer Protocol (XTP) seems to solve many of the problems and has provided packet-video on FDDI networks^{[6][7]}. The Internet Engineering Task Force (IETF) is also developing several draft protocols to handle packet-video applications.^{[8][9][10][11]} It is important to use a standard for the communication, otherwise interoperability once again, becomes a problem.

The major workstation vendors are very aware of these protocol activities and their corporate laboratories are testing various draft protocols. This is to posture the company to be able to deliver the new multimedia protocols on their workstations when they become standard. This should reduce the ill effects of point-designs. It does initially mandate the selection of one computer manufacturer.

III. New Generation Workstations

Improvements to present generation of workstations have made it possible to saturate FDDI networks. In years past, only expensive, high-end computers were able to use the bandwidths delivered at the data-link layer. However, there is still some operating system functions that impact the overall throughput of applications.

Computer system architectures are being refined to meet a perceived interest in collaborative, remote work groups. Reduced instruction set computer (RISC) architectures now have clock speeds exceeding 100 MHz. Workstations vendors generally offer these processors in symmetric multiprocessor architectures which can computationally equal the first CRAY computers. This results in scalable systems where a processors may be targeted for specific functions or the user can let the operating system seek its own optimizations.

Several workstation backplanes now deliver above 1.6 Gbps. Even if the backplane was only 10% efficient, it could operate well at an OC-3 bandwidth (155 Mbps) which is more than enough for tele-ultrasound and tele-fluoroscopy. The operating system easily manipulates data at even higher rates.

For instance, the new SGI Indy workstation, in a standard configuration, can deliver more than 10 frames per second, *uncompressed* video sessions over ATM networks where the frames are 640x480x8 bits. The new SUN, RS 6000 and DEC workstations have the architectures to handle similar data flows. Initially, the performance of these machines is limited by the interface cards. Because ATM is relatively new, few interface cards provide DMA access which is necessary to exploit the full potential of these workstations. DMA cards are available for the high-end SGI machines so that a full 30 frames per second can be processed. Other workstation vendors should have similar offerings.

IV. The Modality Input

Ultrasound uses a National Television Standards Committee (NTSC) signal that is displayed on a CRT or sent to a VHS or super VHS output. Currently, extramural ultrasound interpretation is done by placing the study on a videotape and sending the tape by courier or overnight-mail service to the radiologist. Fluoroscopy has a real-time or near real-time VHS output which usually produces a non-real-time VHS tape for analysis. With ATM, this can be done in a more timely fashion.

With the new generation workstations and an ATM network virtual circuits to provide isochronous data streams, it is now possible for a radiologist to provide valuable feedback to the technologist *during and examination*. Because the information is digital, it is also possible to store key images in a PACS. The proposed system is depicted in Figure 1. The workstation should have an VHS and SVHS (for the video motion-based modalities) connection and an ATM adapter card. The

SGI Indy is equipped with the VHS and SVHS connectors and Fore Systems currently makes the ATM adapter card. Because most workstation vendors are making multimedia product lines, at least the VHS connection should be obtained for the workstation.

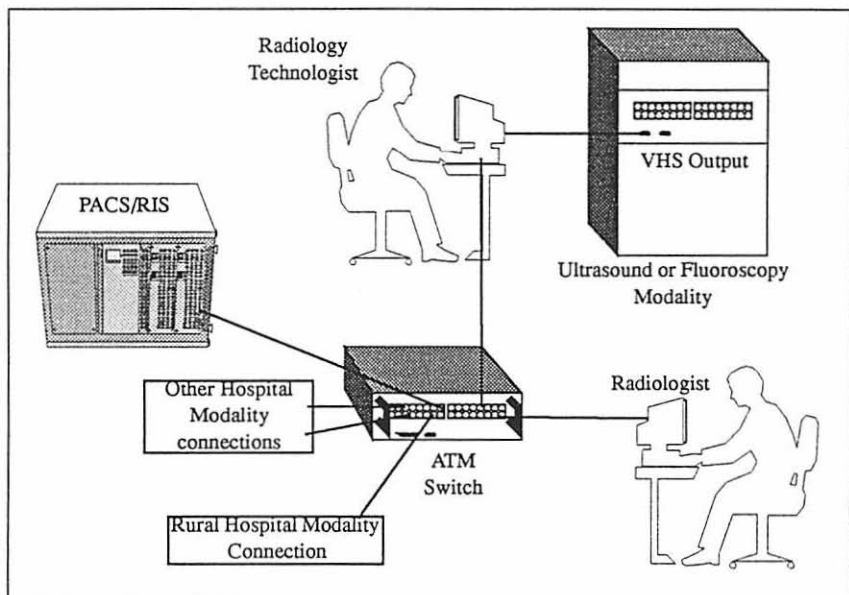


Figure 1 Tele-ultrasound and tele-fluoroscopy connectivity

In addition to the modality connection, the radiologist and technologist will be able to have a teleconference session at the same time. More than likely, this will be an audio-only session as the radiologist and technologist will be discussing the modality protocols in real-time. Such feedback will ultimately improve diagnostic capability and should decrease diagnostic time as the radiologist and technologist will be able to focus attention key areas and functions at the time of the exam.

Because most new generation workstations are capable of teleconferencing, a session could be opened between the radiologist and a primary-care physician with teleconferencing capability. The results can be given to the physician within minutes of the procedure. In addition, the important frames of the study can be played back during the consultation, if that is necessary. In either case, there is much greater potential for radiologist-physician interaction. If a WAN is set up, a radiologist could be provided valuable diagnostic correlation information.

V. CONCLUSIONS

The new workstation and network environments provide a means of replacing frame-grabbed imaging systems with full-motion, uncompressed video with key-image storage and retrieval as an option. These digital media workstations han-

dle all data audio, video, graphics, and standard data. Using available standards, some anticipatory standards, and some point designs, they provide teleconferencing and teleradiology video sequences. With these capabilities, a cost-effective system can be fielded that can provide the radiology technologists with feedback from radiologists that can be incorporated into the study in real-time. The new generation workstations can now deliver ultrasound and fluoroscopy images from its source, to any site in an ATM network with an OC-3 connection. The remote site could be intra-mural or extra-mural.

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SESSION 18

Computed Radiography

Chair: Robert M. Allman

Computed Radiography and Direct Magnification Radiography in Skeletal Radiology—Comparison with Conventional High-Resolution Radiography

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Introduction:

Computed radiography (CR) is used more and more frequently instead of conventional film-screen-systems. One major drawback of computed radiography is a reduced spatial resolution (1,2). In skeletal radiology, however, a high resolution is required to image small bone lesions, e.g. early rheumatic disease can only be diagnosed, if subtle changes of the joints such as loss of cortical white line and subchondral erosions are detected.

In *direct magnification radiography* (DIMA), using a very small focal spot size, the source image distance is increased while the source object distance is decreased. Thus a high spatial resolution is obtained (3,4,5).

Purpose of our study was to increase spatial resolution of computed radiography by using it in combination with DIMA and to compare the diagnostic performance of this technique with high resolution conventional radiography in the evaluation of rheumatic joint lesions.

Material and Methods:

1. Subjects:

This prospective study was conducted between May 1992 and October 1993. 76 patients (mean age 45 years) with signs of early rheumatic disease were examined with both conventional and magnification radiography. Informed consent was obtained from all patients. Regions radiographed with CR and DIMA included hand (carpal region: 19 cases, metacarpo-phalangeal and interphalangeal joints: 43 cases) and feet (18 cases). 80 corresponding radiographs obtained with each technique were analyzed.

2. Imaging techniques:

2.1. Magnification radiography system:

The prototype (Microfox G10, Feinfocus Medical Systems, Garbsen, Germany) of a newly developed microfocal X-ray tube was used. This prototype was microprocessor-controlled and performed at variable focal spot sizes between 20 and 130 μm . Direct magnification radiography up to 9 fold could be achieved. The microfocal X-ray tube was demountable allowing easy replacement of filament and target; a two-stage pump system produced the operational vacuum (6).

All patients were examined with a five fold magnification, 50 kVp and a focal spot size of 60 μm . A detector dose of 1.25 μGy was used. The radiation dose was measured using a dosimeter (ionization chamber, Type 7733, PTW, Freiburg, Germany). The exposure dose was 1.3 fold as compared to conventional radiography and the average exposure time 0.71 s.

2.2. Computed radiography system:

As an imaging system computed radiography was used employing storage phosphor technique (FCR-7000 storage phosphor unit, Fuji, Tokyo). Cassette size was 35x43 cm with a pixel length of 200 μm i.e. a matrix size of 1760x2140. Therefore the theoretical limit of spatial resolution was 2.5 line pairs per millimeter (lp/mm). X-ray adjusted images were obtained and additionally the digital images were processed (AC-1, Fuji, Tokyo) using unsharp-mask filtering to produce edge enhanced radiographs. Among several filtering algorithms a program was chosen imaging bone structures with high contrast, avoiding halo effects.

2.3. Conventional screen-film combination:

Using a conventional X-ray system patients were radiographed with a focal spot size of 600 μm and 44 kVp. A mammographic high-resolution film-screen-system with a detector dose of 80 μGy was employed (film: MinRM, Kodak, screen: MRM-1, Kodak, Rochester, NY). The spatial resolution achievable with this film-screen-combination is 9 lp/mm at 20% of the modulation transfer function (MTF).

3. Image analysis:

All images were analyzed by five experienced radiologists. A total of 160 radiographs was analyzed by each of the five readers. A Receiver operating characteristic (ROC) analysis (7) was performed. Each image was placed on a separate sheet of film to permit treatment of each anatomic section as an independent observation. To prevent learning bias all images were shown in random order and not more than 45 images per session were reviewed. Time in between reading sessions was at least 96 hours. The five radiologists were without knowledge of lesion location. Each was permitted to use a magnifying glass and a bright light. Throughout the reading sessions, ambient light was kept at a minimum, and no time constraints were used.

The readers were asked to state whether they were able to detect the presence or absence of a lesion on each single image and to diagnose rheumatoid joint disease. They then assigned one of 4 levels of confidence (1 = definitely negative, 2 = probably negative, 3 = probably positive, 4 = definitely positive). Location had to be stated for each lesion, in case of discordance lesions were rated as false positive. Pooled, averaged and individual reader data for a total of 800 observations (400 per imaging modality) were analyzed. An expert's panel (composed of a rheumatologist and a radiologist experienced in rheumatology who analyzed the images, knowing the results of all clinical investigations and the laboratory findings) and the patients' follow-up studies were used as a reference.

ROC curves were obtained by use of a maximum-likelihood curve-fitting algorithm. Lesion detectability was estimated by the area under the ROC curve (AUC).

In addition interobserver analysis was performed. During ROC-analysis all five readers were also asked to evaluate the quality of anatomical structures, such as the depiction of the joints, the trabecular bone pattern and the cortical white line. These had to be graded according to a 4 level scale (excellent=4, good=3, satisfactory=2, poor=1). Additionally they had to grade the quality of pathological structures, such as soft tissue swelling, juxta-articular osteoporosis, loss of cortical white line and erosions.

In both, ROC and interobserver analysis, the significance of differences between observer performance with both modes was tested with Student paired T test (8) for individual ROC areas and gradings in interobserver analysis.

Results:

ROC-analysis showed, that each of the five readers performed substantially better with the magnification technique as compared to the conventional technique. Using pooled data for all readers, direct comparison showed a larger area under the curve (AUC) for magnification radiography (0.80) as compared to conventional radiography (0.72) (Fig.1). This difference was statistically significant at $p < 0.02$. Using magnification radiography both pathological and non-pathological images were diagnosed with a higher degree of confidence. Therefore detection of early rheumatoid lesions was improved by magnification radiography.

Fig.1: ROC curves from pooled data for all of the five readers. Comparison between DIMA (AUC=0.80) and conventional radiography (conv) (AUC=0.72) showing significantly ($p < 0.02$) better detection of rheumatoid joint lesions.

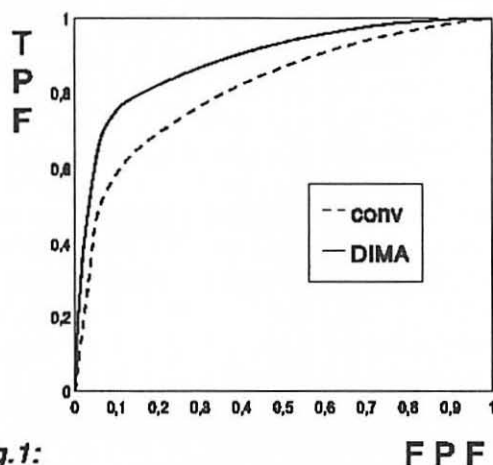


Fig.1:

F P F

Retrospectively several lesions, that were not diagnosed in conventional radiography at first, could actually be seen knowing their location and morphology, which was due to the superior contrast in the magnification radiographs.

In *interobserver analysis* all of the anatomical structures evaluated (depiction of joints, trabecular bone pattern and depiction of the cortical white line) and a part of the pathological structures (soft tissue swelling, loss of cortical white line and erosions) received better gradings with the CR/DIMA-technique as compared to the conventional technique. Both average and all of the individual scores were significantly higher ($p < 0.02$) in magnification radiography. Concerning juxta-articular osteoporosis, however, the score was not significantly improved.

Discussion:

Previous studies (3,9-12) have suggested, that the application of magnification radiography in the diagnosis of early rheumatic disease may be superior to conventional radiography. However, due to the limited life span of the microfocal X-ray tubes, increased radiation dose and low performance in using a small focal spot size magnification radiography is not established in clinical routine (3,4,5,13). With new technical developments it was possible to design a microprocessor controlled microfocal X-ray tube with long durability, designed for up to 9 fold magnification in clinical routine use (6). In this study we had the opportunity to test the first prototype of the newly developed direct magnification X-ray tube using CR.

There are four important *advantages* of computed radiography as compared to conventional film-screen combinations (1,2,14,15):

1. Increased visualization of tissues of various density as a result of the wide latitude of the detector system,
2. improved image quality due to processing, such as unsharp mask filtering and gray-scale image processing,
3. by using the automatic image processing capabilities repeats caused by exposure error are eliminated and
4. digital communication and archiving is possible.

As discussed previously (14,15,2) one potential *disadvantage* of computed radiography, however, is an inferior spatial resolution. The resolution of computed radiography can be increased by using it in combination with magnification. Previous studies (15,16) proved, that in more than five fold magnification radiography the overall resolution is determined by the geometrical setting (focal spot size) and not as much by the imaging system (e.g. film-screen-system). Thus there are no significant differences in spatial resolution between computed radiography and film-screen-systems.

The high contrast, which can be achieved by using image processing in computed radiography has to be considered as a factor of improved image quality, which may not only be the result of direct magnification radiography.

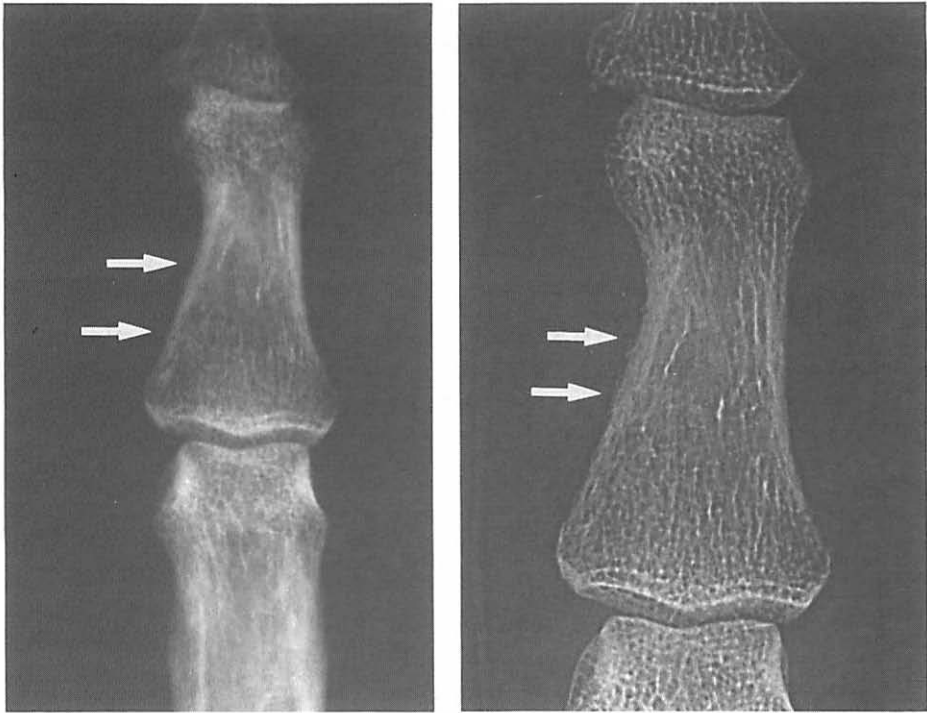


Fig.2: 31-year-old caucasian male with swelling of fingers and joints for 10 months. Optically magnified conventional radiograph (left) and DIMA radiograph (right) of the middle phalanx. Periostitis with proliferations as a sign of early psoriatic arthritis only detected in edge-enhanced DIMA radiograph.

Since magnification radiography requires longer exposure times and there is no significant reciprocity failure in CR as compared to film-screen-systems, *exposure dose* can be reduced. Additionally kVp values were increased (50 kVp) and detector dose was reduced ($1,25 \mu\text{Gy}$) to decrease radiation dose. This resulted in an exposure dose which was 1.3 fold higher, as compared to conventional radiography. The increased dose, however is acceptable since clinically only hand and feet are radiographed with a small field of exposure. Two *disadvantages* of magnification radiography, however, cannot be overcome; these are the limited field of view (with 5 fold magnification and a cassette size of $43 \times 35 \text{ cm}$ the field size is $8.6 \times 7 \text{ cm}$) and the long exposure times. Therefore, if a larger field of view is required, direct magnification radiography can only be used with a reduced magnification,. Moreover with 5 fold magnification this technique is merely an additional method in case of equivocal findings in conventional radiography (e.g. early rheumatoid arthritis, monitoring of disease progression).

Because of long exposure times (hand and feet: 0,6 s, femur and hip joint: 3,0 s) so far only the extremities can be examined, without motion artifacts (17).

In conclusion, our results show that magnification radiography used together with computed radiography is superior to high resolution conventional radiography in the detection of small erosive and proliferative bone lesions. Thus one major disadvantage of CR can be overcome and the radiologic evaluation of rheumatic, infectious and metabolic joint and bone disorders may be improved.

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Image Optimization by Dynamic Range Control Processing

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Introduction

Fuji Photo Film Co., Ltd. announced the concept of Computed Radiography(CR) at the ICR held in Brussel in 1981 and introduced its first generation product model, FCR101 in 1983 (1). Since then, two types of digital image processing have been widely used in a daily clinical routine: contrast processing and spatial frequency processing (2). With the combination of these two types of image processing, one can enhance the contrast and/or edges of the anatomy of interest. Furthermore, a wide visible range for diagnosis is realized when the spatial frequency processing is optimally combined with the contrast processing. These advantages seem to have been well accepted clinically. However, as the use of the CR becomes popular, it is becoming clear that there is a wider spectrum of clinical demands for the digital enhancement. One typical example is a case where an observer demands wide dynamic range, but not strong edge enhancement, for some clinical reasons.

Against this background we have developed a new image processing algorithm, dynamic range control processing(DRC), which can control the dynamic range of the CR image independently from the contrast and frequency processing. Initial results indicate that this new processing algorithm can provide wide visible range for diagnosis in most examinations. In addition, We found that a careful optimization of the processing parameters is a critical factor in achieving clinically useful enhancement. In this paper we will discuss the basic principle of the DRC and several case studies for optimizing the DRC parameters.

Basic principle:

A basic concept of DRC processing is using the digital unsharp mask technique. After the unsharp mask signal is calculated from the original signal, a necessary density range of the mask signal is extracted and superimposed on the original data. This processing is described with a following equation:

$$SD = Sorg + \beta f(Sus) \quad (1)$$

where:

$Sorg$ is an original image signal,

Sus is an unsharp mask signal,

$f()$ is a look-up-table to extract a necessary density range from the unsharp mask signal, and

β is a weighting factor to add the extracted unsharp mask signal on the original signal.

Furthermore, the unsharp mask signal here is described by a following equation:

$$Sus = \frac{\sum Sorg}{M^2} \quad (2)$$

where M is a kernel size.

One simple example of how equation(1) works on the image data is summarized in Fig.-1. Fig.-1(a) shows an original signal in 10-bits gray scale. In this case we take a step wedge as an example. Figure-1(b) shows a smoothed signal after the unsharp mask processing. Fig.-1(c) and (e) demonstrate two different types of look-up-tables, i.e., $f()$ in the equation(1). The look-up-table shown in (c) extracts the lower optical density part of the image pixel value which lie between 0-511 in the 10-bits image. Then this extracted signal is added on the original signal shown in (a), yielding a resultant signal(e). In this case, signal components in a low density range now exhibit a higher density. The table shown in (d) extracts the higher optical density part of the image; lie between 600-1023 in the 10-bits image. This time the $f()$ has a negative value, so the extracted signal is subtracted from the original signal, yielding the resultant signal (f). In this case, the signal components in the high optical density range now exhibit a lower density.

The step wedge in Fig.-1 represents large structures such as the lung fields, heart, and the mediastinum, while the minute signal variations over each step denote finer structures such as lung vasculature or intervertebral spaces in the mediastinum. If we use this analogy and again observe the effect using the look-up-table in (c), it is easily understood that this table can be used to display both mediastinum and lung field simultaneously in a single image without losing contrast on either structure. The effect of such DRC processing is visually demonstrated in Fig.-2 using a chest image. Fig.-2(a) is an original image of a typical chest examination. The Fig.-2(b) is a filter image, which corresponds to $f(Sus)$ in the equation(1). On this image a lower density range of the unsharp masked signal is extracted using the look-up-table shown in Fig.-1(c). Finally this filter image is added on the original image (a) with a weighting factor(β). The resulting image is shown in Fig.-2(c).

Parameters to control the DRC.

We use three parameters to control the behavior of DRC. Instead of manipulating detailed parameters appearing in equations(1) and (2), we use simplified parameter definitions. This is necessary because the DRC is being

used in the daily clinical routine. Following is an explanation of these three parameters.

1) DRN : This parameter controls the kernel size(M) in the equation(2). We prepare ten steps: 0 through 9. A smaller value for DRN means a larger kernel size. A smaller

DRN value provides a less sharp filter image such as the one shown in Fig.-2(b). If the filter image is insufficiently blurred, it might contain singular components corresponding to anatomy of major interests such as pulmonary vessels and the final process, i.e., the addition of the filter image on the original image, may result in poor local contrast for an important anatomy. Therefore, a DRN value which provides relatively large kernel size compared to structures of interest is preferred.

2) DRT: This parameter defines a shape of the look-up-table, i.e., $f()$ in equation (1). Eight types (A through H) are available. (Fig.-3) With A through D, lower density regions are extracted. With other four types, higher density regions are extracted. The DRT chosen should be appropriate for the anatomical region over which the dynamic range needs to be controlled. For example, to control the dynamic range of the mediastinum in chest images, DRT of B is usually preferred.

3) DRE: This parameter is a weighting factor, i.e., β in equation-(1). This parameter can be changed over the range 0.0 through 2.0. A larger value provides a greater density shift on the area extracted by the DRT.

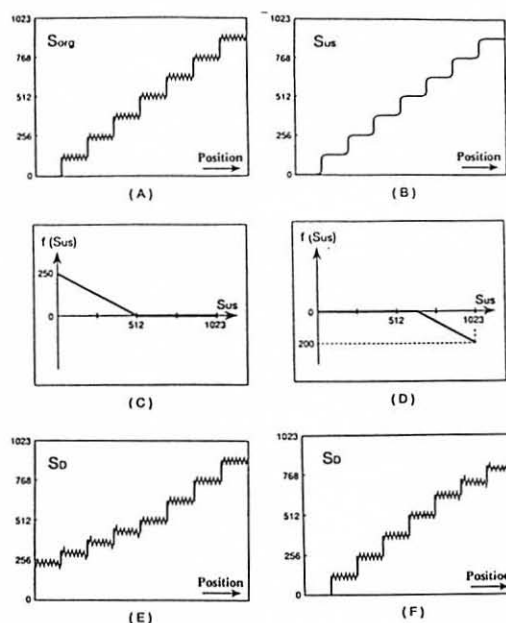


Fig.-1 Principle of DRC processing

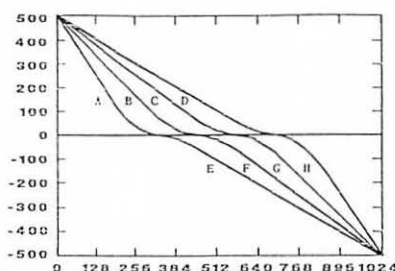


Fig.-3 DRT parameter curves

Result:

We applied DRC to several typical types of examinations and found optimal parameter combinations.

1) Chest image.

In the case of the chest, the image display with a higher contrast is usually preferred. However, an increase of the contrast immediately leads to the saturation of the least dense region. More specifically, if we increase the contrast for the lung, density in the mediastinum part will be easily lost. Such a dilemma can be solved when we apply the DRC. Fig.-2, which is already used to explain the principle of the algorithm, shows the chest image processed with DRC. The parameters are: DRN=2, DRT=B, DRE=0.6.

2) Breast image.

In the case of the mammography, a dense breast is a typical example for DRC. Similar to the case of the chest, one prefers to use higher contrast to visualize the breast. However, this leads to a loss of the information around the skinline. In order to avoid such a dilemma, dynamic range of the higher density regions can be controlled. Fig.-4(c) shows a breast image processed with DRC. To control the highest density regions, the DRN=2, DRT=F, and DRE=0.6 values are used.

3) Extremity image.

With extremity images, it is preferable to display both bone and soft tissue simultaneously with high contrast. One method to achieve this goal is the use of edge enhancement combined with a contrast processing which provides a rather lower contrast or wider latitude. However, strong edge enhancement sometimes provokes a severe over/undershoot artifact around a sharp edge such as on the artificial bone or metal. Using DRC, it is possible to control the density range for the soft tissue without losing contrast. Fig.-5(c) shows an DRC image processed with the DRN=2, DRT=F, DRE=0.6.

Conclusion:

We have developed dynamic range control processing(DRC) and introduced three types of parameters to control its effect on the image. We have demonstrated that an optimization of these parameters can provide enhanced diagnostic quality on CR image.

References:

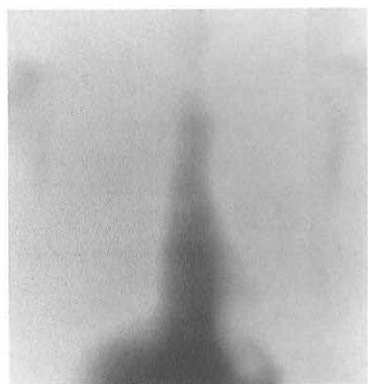
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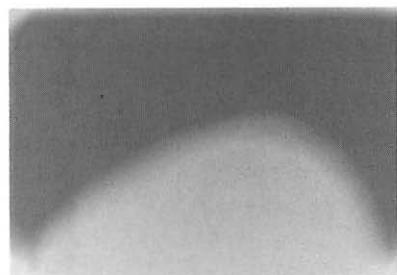
(a) Original image



(a) Original image



(b) Filter image



(b) Filter image



(c) DRC image



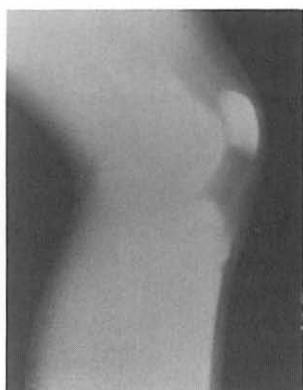
(c) DRC image

Fig.-2 Example of DRC image (chest)

Fig.-4 Example of DRC image (breast)



(a) Original image



(b) Filter image



(c) DRC image

Fig.-5 Example of DRC image (bone)

Adjustment of Dose to Required Image Quality Using Signal-to-Noise Ratios

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Purpose

Computed Radiography provides a wide dose range. Exposures with low dose result in noisy images with lower image quality. This increase in noise is the limiting factor for further decrease in dose. The study intended to evaluate the lowest acceptable dose in radiographs by simulating different exposures by artificially introducing noise.

Material and Methods

The system used for this study was a Computed Radiography system (Digiscan, Siemens based on FCR 7000, Fuji). The signal-to-noise ratios (SNR) for different doses were measured using a homogeneous absorber. The distribution of the gray values was analyzed and compared with the gaussian function.

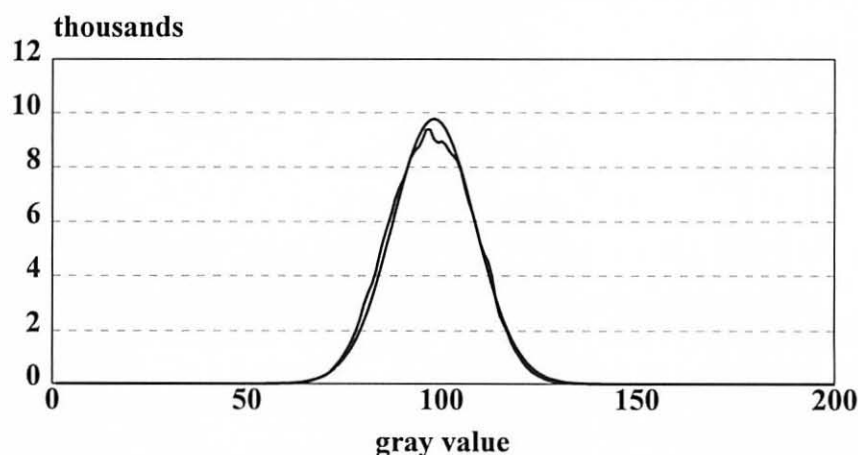


Figure 1: Histogram of gray values, measured with homogenous absorber and theoretical calculated corresponding gaussian function.

The sigma in this function was the standard deviation of the gray values, the center was the mean gray value. For simplification the dose distribution was not calculated, because for the applied small dose ranges the transformation can be accepted as linear instead of logarithmic. The differences between the gaussian function and the histogram for a matrix of 512 x 512 are small and allow the use of the gaussian function to describe image noise (fig. 1).

From the measurements of the SNR's the sigma values were calculated in terms of absolute dose. This corresponds to the standard deviation of dose in relationship to mean dose. Using these results, a function based on

$$SD(\text{noise}) = \text{SQRT}(A * \text{dose}) + B \quad (1)$$

simulating quantum and system noise was fitted using the SPSS statistics program. R squared for this fit was about 0.99. (fig. 2)

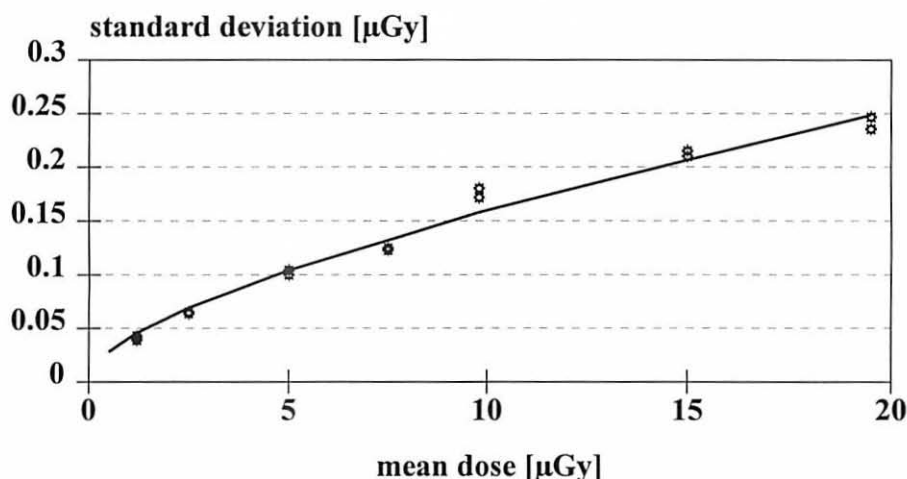


Figure 2: Standard deviation measurements as a function of mean dose. The curve represents the fitted function.

For each pixel in the digital image the corresponding dose and standard deviation was calculated and the same was done for the image, which should be generated. The calculation of the dose of one pixel was done using the formula:

$$\text{Dose} = \text{const} / \left(S \text{ factor} * \exp_{10} \left(L \text{ factor} * \frac{I - 511}{1024} \right) \right) \quad (2)$$

where the S factor is the intensifying factor, the L factor is the dose range taken into account, both are printed on the film. I is the gray value measured at the workstation and the constant is a function on kVp and screen type, but is about 1000.

Since the noise is gaussian and the descriptive parameters in the original and in the image which should be calculated are known, it is possible to estimate the sigma for the gaussian function of the additional noise. The sigmas can be calculated using the formula:

$$\sigma_{\text{conv.}}^2 = \sigma_{\text{real}}^2 + \sigma_{\text{arti.}}^2 \quad (3)$$

where $\sigma_{\text{conv.}}$ is the sigma for the convoluted gaussian function, σ_{real} is the sigma for the noise in the real image and $\sigma_{\text{arti.}}$ is the sigma for the gaussian noise which is artificially additionally introduced. The difference between the convoluted gaussian function and calculated function is very small (fig. 3).

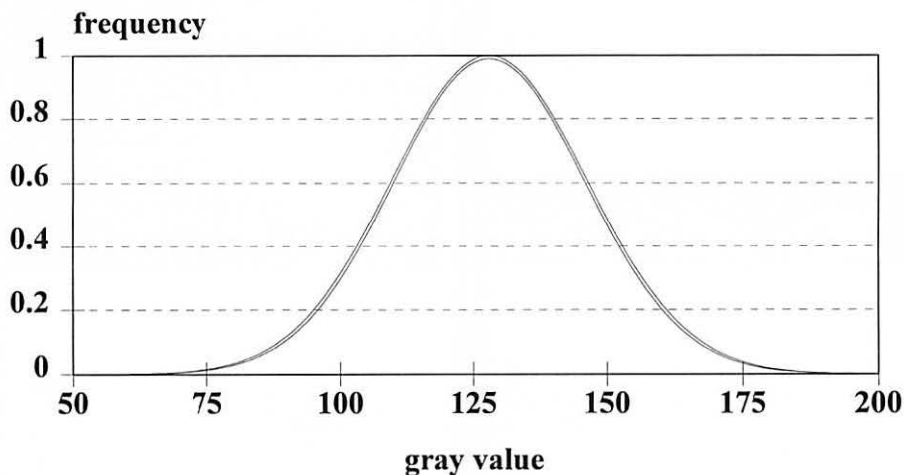


Figure 3: Difference between convoluted and theoretical gaussian function

These results were applied to clinical images. The new mean dose can be chosen freely but must be lower than the applied dose of the original image. The program for the generation of an artificial image was written in Fortran, CPU time for each image is about 15 min on a MicroVax II.

To verify the theoretical derivation a chicken was exposed with different doses. Using the image obtained with the highest dose, the other dose values were simulated. Figure 4 shows the original image (a) and an image calculated from this one (b) simulating the same dose as used in (c).



(a)

Figure 4:

- (a) Image of a chicken obtained with an exposure of the image plate with 20 μGy (top left).
- (b) Image simulating a dose of 1.3 μGy (bottom left). The image noise was introduced artificially.
- (c) Image obtained with a dose of 1.31 μGy at the image plate (bottom right).



(b)



(c)

The first clinical application is the possibility to reduce exposure images of infants in hip dysplasia examinations. To these images noise was added digitally to simulate different doses. In clinical routine the exposure of the image plate is about 2.5 μGy comparable to a film screen system with a speed of 400. The doses simulated were 1.5 μGy , 1 μGy , 0.75 μGy , 0.5 μGy , 0.25 μGy , and 0.15 μGy . The hardcopies of the processed images were analyzed by four readers.

Results

The lowest dose accepted for measuring acetabular angles, Shenton's line and the angle of the femoral neck varies between 0.5 μGy and 1.0 μGy . These results were subsequently chosen for clinical routine, thus the dose for the image plate is now reduced from 2.5 μGy to 1.0 μGy . Due to the very short exposure times in young infants, this could only be achieved by additional filtering. However, the radiologists differ in their opinion of required image quality.

Conclusion

This experimental procedure can be used to minimize patient dose **without any extra exposures**. It is transferable to all other digital examinations and easy to perform with the software available. With this algorithm applied to other examinations a general reduction of dose in computed radiography is achievable. However, there are some problems: the influence of scatter is not taken into account in this study. This is very difficult to include, especially if an antiscatter grid is used. Furthermore there are a few approximations in calculation of the additional noise, resulting in slight differences from calculated and obtained images of same dose.

The method of simulating different doses in Computed Radiography will be evaluated furtheron., Analysis of the influence of scatter, different dose ranges and convolution filters will be the next steps.

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ROC Evaluation of Computer vs Computed Radiography (Film) Radiographs

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The question of whether there are significant differences in diagnostic accuracy between viewing conventional or computed radiography (CR) film radiographs versus radiographic images displayed on a CRT monitor must be addressed if the transition to filmless (digital) radiology is to be successfully implemented in the clinical environment. To this end, there have been a number of studies which have compared observer performance using film versus CRT displays. The results have, overall, been equivocal.¹⁻³ Sometimes there are no significant differences between performance with film vs CRT, sometimes film yields better performance than CRT, and sometimes CRT viewing is better than film. As workstation and monitor technology becomes more sophisticated and refined, the differences in observer performance between film and CRT viewing are becoming smaller. In some cases, as with the MDIS system at Madigan Army Hospital, the move has already been made to a totally digital radiology department.⁴ Questions still remain, however, as to whether all types of studies (e.g., mammography) can be diagnosed accurately using CRT monitors, and whether primary diagnoses can be carried out using CRT monitors.

In addition to diagnostic accuracy, there are other factors that must also be considered in evaluating the utility and acceptability of converting the radiological viewing environment from film to CRT. One important factor is time. Is the time to review an image on a workstation CRT at least as short as the time it takes to review a film image? If not, then radiologists are not likely to accept the slower method, especially in departments with high case-load traffic. Another important factor is image quality. Is the visual quality and visibility of important diagnostic structures comparable for CRT and film viewing? And in a broader sense, is the image aesthetically pleasing to look at?⁵ If not, then diagnostic accuracy

may be affected significantly. Finally, and more relevant to workstation design, is the question of what types of image processing or manipulation functions should be made available to the radiologist for use on a workstation? Investigations into what the radiologist needs and actually uses are quite important in this respect. If the radiologist cannot deal with complicated menus and only uses a few image processing functions, then systems should be designed to suit their needs and improve the human-computer interface.

METHODS & MATERIALS : In the present investigation, the suitability of using an image console monitor (FUJI HI-C500 workstation) for interpretation of adult portable chest radiographs was evaluated using ROC analysis and subjective techniques. This workstation was designed for viewing images processed by the Fuji FCR AC-1 PLUS CR system. The console has a high-resolution 20-inch horizontal monochrome CRT (1,024 x 1,538 pixels, 60-Hz noninterlaced scanning). The system provides a number of on-screen image-processing (e.g., enlarge/zoom, edge enhance, window/level) and image manipulation (e.g., rotate, flip) functions.

Over a 3-month period, 80 adult portable CR chest radiographs were selected from approximately 300 radiographs of patients in the ICU at the University of Arizona Medical Center (40 with subtle instances of subsegmental atelectasis (AT), 40 with a single subtle pneumothorax (PT)). Each radiograph was interpreted by an experienced radiologist not participating in the study, and diagnoses were confirmed by checking the original diagnostic report. Image quality was also rated by the radiologist, and only those images rated as excellent were included in the study. The final test set consisted of the 80 CR film images and 80 soft-copy versions of the same 80 images stored on optical disks.

Six board certified radiologists read the 80 chest images, once on the workstation display monitor and once on CR film, for the presence/absence of a pneumothorax or atelectasis. Confidence in these decisions was reported using a 6-level scale where 1 = definitely no active disease (NAD) and 6 = lesion (AT or PT) definitely present. Judgments of correct/incorrect positions of five different tubes and lines (nasogastric, chest, endotracheal, Swan-Ganz, central line) were reported using a 5-level scale : 1 = definitely OK, 2 = probably OK, 3 = probably not OK, 4 = definitely not OK, 5 = cannot tell. Total viewing time was recorded by videotaping the sessions.

Throughout the experiment a counter-balanced design was used for image presentation, and approximately 2 weeks intervened between successive viewing sessions to offset any practice effects. The presentation order during each session was randomized in a different order for each observer. Practice sessions were also given before each session to familiarize observers with the workstation and the appearance of the images on the workstation. At the end of the final session, the observers completed a subjective evaluation of the workstation, rating the overall quality of the images, the visibility of 10 specific diagnostic structures, and the ease of interaction with the workstation.

RESULTS : A summary of the major results is presented in Table 1. Individual Receiver Operating Characteristic (ROC) curves were generated, and area under the curve (Az) and standard deviation values were computed using the decision confidence ratings for the film and CRT conditions. To test for statistically significant differences between the two viewing modes, a Student's t-test for paired observations was employed. Separate analyses were conducted for the AT and PT cases (each set with matched NAD cases).

A statistically significant difference ($p = .03$) was found in favor of CRT monitor reading for the detection of pneumothoraces (CRT Az = 0.789 (SD = .07) vs Film Az = 0.706 (SD = .06)). Atelectasis detection was also higher with monitor reading (CRT Az = 0.934 (SD = .03) vs Film Az = 0.903 (SD = .05)), but the difference did not reach statistical significance ($p = .28$). An analysis of the percentage of true-positive (TP) and false-positive (FP) reports revealed that overall the percentage of true-positive reports was higher for CRT viewing (CRT = 75% vs Film = 72%), and the percentage of false-positive reports was lower for CRT viewing (CRT = 16% vs Film = 19%) than for film.

Tube/line position judgments were equivalent for both modes. The data were analyzed by determining the percentage of times each observer gave the same or different confidence rating (how confident that tube/line position is correct/incorrect) for the same image on the CRT and film. There was complete agreement of reported confidence for 63.18% of the tubes/lines. The percent increases to 85.66% if one considers only OK (ratings 1 and 2 combined) vs not OK (ratings 3 and 4 combined) judgments.

Total viewing time was about one minute longer per image with the monitor than with film viewing (CRT = 99.82 sec vs Film = 33.63 sec). This difference was statistically significant

when tested with a Student's t-test for paired observations ($p = .0001$). This viewing time did not include the time it took to carry out the command sequences and wait for the workstation to remove an old image and bring up a new image, or the time to remove a film image and put up a new one. On average, the between image time was 13.7 sec ($SD = 3.9$) for the workstation vs 5.2 sec ($SD = 1.1$) for film. The difference was statistically significant ($p = .002$).

TABLE 1. Summary Results of CRT vs CR Film Viewing.

	<u>CRT</u>	<u>CR FILM</u>
Mean Az PT	0.789 ($SD = .07$)	0.706 ($SD = .06$)
Mean Az AT	0.934 ($SD = .03$)	0.903 ($SD = .05$)
Overall % TPs	75%	72%
Overall % FPs	16%	19%
Mean Viewing Time	99.82 sec	33.63 sec
Mean Between Image Time	13.7 sec	5.2 sec

Tube/Line Position Agreement = 85.66%		
Image Processing Use : window/level = 97%		
zoom = 37%		

An analysis of the frequency of use of the image processing functions available on the display monitor was also conducted. Although a number of image processing functions were available, the radiologists used only window/level (97% of the time) and zoom (37% of the time) on a significant number of cases. The other functions (e.g., gamma-correction, edge enhancement) were used infrequently or not at all.

With respect to the subjective ratings of the workstation given at the end of the final viewing session, the overall quality of the CRT presented images was rated as being the same as or somewhat better than film. The visibility of the various diagnostic structures (e.g., tracheal air column, lung interstitium) was rated on average as being the same as film. The visibility of tubes/lines was rated as better than film. Overall, the workstation received good ratings (i.e., the same as or better than film) for such factors as image quality and visibility of diagnostic structures; but was rated poorly (i.e., worse than film) on "user friendliness" and

ease of use. The amount of time it took to manipulate and diagnose the images was also judged to be unacceptable for clinical use.

CONCLUSIONS : It was concluded that viewing CR images on a workstation does not seem to affect diagnostic accuracy compared to film viewing, and may in fact represent a significant improvement especially for detection of pneumothorax. For both pneumothorax and atelectasis Az detection performance was higher for CRT viewing than for film. The analysis of percentage of true- and false-positive reports confirmed this result - the percentage of true-positive reports was higher for CRT than for film and the percentage of false-positive reports was lower. The ability to judge the correct position of tubes/lines was comparable or even better for CRT and film reading. The fact that the visibility of tubes/lines was judged to be better for CRT than for film seems to explain why this should be the case.

Although diagnostic accuracy was comparable for CRT and film viewing, viewing time was not. On average it took one minute longer per image for CRT viewing vs film viewing. This did not include between image time, which was also significantly longer for CRT vs film viewing. The viewing time results indicate one of the major problems with CRT viewing - it takes an unacceptable amount of time to diagnose an image. Case-load throughput is extremely important in most, if not all, radiology departments. Any factor which slows down throughput time is generally unacceptable, especially if it is related to the actual reading process. An analysis of the videotapes of the CRT sessions indicated that not only was the increase in time due to the fact that the radiologists needed more time to manipulate the images (i.e., use the image processing menus and wait for the results), they also spent more time during the diagnostic decision process. Part of this problem could be eliminated by developing preset image processing defaults tailored to the individual radiologist. This might help decrease viewing times to within acceptable levels, by allowing the radiologist to concentrate more on the diagnostic tasks and less on the image manipulation tasks.. More extensive experience with CRT viewing systems in general may also influence viewing times.

The use of presets for the image processing functions is also suggested by the results of the analysis which looked at the use of the various image processing functions. Overall, the radiologists mainly used the window/level function, and it seemed to be used primarily for increasing the visibility of the

tubes/lines. The zoom function was used in just a little over one-third of cases, and according to the radiologists it did not affect their diagnostic decisions to a very large extent - it was merely a confirmatory exercise. The results of this analysis suggest that for most cases a simple menu which offers only window/level and zoom capabilities would suffice. Other more elaborate image processing functions (e.g., edge enhancement, gamma correction) could be available for use, but they could be relegated to a secondary menu to be accessed when desired. This would improve significantly the "user friendliness" of the workstation environment and possibly improve the ease with which radiologists make the move from film to CRT viewing of radiographic images.

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A Comparison of CCD-Based Intraoral Radiographic Systems and Digitized Film-Based Radiographs

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CCD Dental Radiographic Systems allow the immediate production of an image, potentially expediting treatment such as endodontics and dental implant placement procedures. If the exposure is incorrect for the patient, this is seen immediately and can be adjusted before further exposures are made. It means no darkroom, no processors, no film for the practitioner to purchase, and no processing solutions for her to buy; additionally, there is no tracking of contaminated film packets around the office to the darkroom.

A variety of CCD-based intraoral radiographic systems have been introduced for teaching and research activities in the clinical and laboratory areas of the Division of Radiology and Imaging Sciences, University of Louisville School of Dentistry. These systems are: RVG-S (RadioVisioGraphy-S) and RVG-PCi (Trophy Radiologie, Vincennes, France), Flash Dent (Villa Sistemi Medicali, Buccinasco, Italy), VIXA (Gendex Corporation, Milwaukee, Wisconsin), and Sens-A-Ray (Regam, Sundsvaal, Sweden). The specifications of these systems, together with one other not present in our laboratory (CDR: Schick Technologies, Long Island City, NY) are listed on the next page (Table I). As of March, 1994 all of these systems had gained FDA approval for use in clinical &dentistry.

There are two major variants of CCD device for intraoral radiography; namely, those that

operate by "fluorescence" producing light from incident x radiation using a scintillation screen, and those that use CCDs which are directly sensitive to x

TABLE 1: APPROVED CCD SYSTEMS FOR INTRAORAL RADIOGRAPHY

SYSTEM	SENSITIVE AREA (mm)	PIXEL MATRIX	PIXEL SIZE(µm)	DYNAMIC RANGE	OPTICS
RVG-S RVG-PCi	275x182	480x380	60x60	8 bit	YES
Sens-A -Ray	259x173	576x385	45x45	8 bit	NO
VIXA	240x180	384x288	63x63	8 bit	NO
Flash Dent &	240x200 240x300	480x400	50x50 50x85	8 bit	YES
CDR	209x147 346x192 365x252	436x306 720x400 760x524	48x48 48x48 48x48	8 bit	NO
FILM #0	350x220	N/A	N/A	Analog	NO
#1	400x240	N/A	N/A	Analog	NO
#2	410x310	N/A	N/A	Analog	NO

radiation. Those using fluorescence employ optics to channel light to the CCD via an optical couple (a fiber optic prism for the RVG systems; a series of seven lenses for the FlashDent). Such optical systems permit the use of CCDs with a smaller surface area than the required sensitive area as unlike x radiation it is a simple matter to focus light. Additionally, the use of optics allows the use of CCDs that are more sensitive to radiation by use of glass that is translucent to light but resistant to the passage of x radiation (e.g. the fiber optic prism for the RVG systems is constructed from tapering tungsten glass fibers).

The other three CCD devices which are commercially available use "hardened" CCDs with a surface area sufficient to receive the whole image. The major advantage of these systems is the direct response of the CCD to x rays creating the latent image, rather than the use of scintillator. This generally results in a greater spacial resolution for the image, however, it is accompanied by an increase in the background haze or "noise."

Direct emulsion film is used for intraoral radiography. This is sold in various sizes and speed groups. The most commonly used radiographic film presently is speed group D (e.g. Ultraspeed: Eastman Kodak, Rochester, NY), but patient dose can be reduced by almost 50% by use of speed group E film (e.g. Ektaspeed: Eastman Kodak). This film being analog permits a continuous range of gray shades. The spatial resolution is 12-14 lp/mm. These radiographs can be digitized using a flatbed scanner, (e.g. XRS Scanner: XRS Corporation, Torrance, California) and various dpi resolutions can be selected.

Determination of the imaging characteristics of the various modalities has been carried out in a number of studies in our laboratory. The investigations have included perceptibility tests using a standard aluminum test object and extracted teeth, linearity evaluations, measurement of spatial resolution, and determination of dose dynamics using a beryllium windowed ionization chamber (PRM Inc., Nashville, Tennessee). This paper summarizes the key findings of these studies.

(1) DOSIMETRY: Dosimetric considerations require both a maximum and minimum permissible dose which permits the desired task to be performed. This is dependent upon the use of the enhancement capabilities of the system and also upon the task being applied. Dosimetric studies that restrict the evaluation to the initial linear digital image and are dependent on subjective rather than objective quality criteria are flawed. For this reason two specific tasks have been applied at our institution; namely, perceptibility curve determinations with aluminum test objects and determination of the length of endodontic instruments in root canals.

In the latter case it proved possible with the RVG 32000 to effect dose reductions up to 90% against E speed film and up to 94% against D speed film in this task with the use of contrast gradient enhancement (1). The newer generation or RVG-S and RVG-PCi do not effect such a magnitude in dose reduction as measured by perceptibility tests. Visually equivalent images could be achieved with exposures of 42-55% less with the present generation of RVG as compared to E speed film (2). Comparisons of the RVG-S and the VIXA showed the VIXA (0.34-1.24 microGray) to have a dose dynamic of one-fifth of that of the RVG-S (0.34-5.95 microGray), but to effect similar dose reductions when compared to film (3).

RESOLUTION: Resolution was measured using a standard grid. For both D and E speed film the resolution measured was 14 line pairs per millimeter (lp/mm). The resolution measured for the CCD based sensors was: Sens-A-Ray 10 lp/mm; RVG-S 9 lp/mm; VIXA 8 lp/mm and FlashDent 4 lp/mm (3,4).

PERCEPTIBILITY: Using an aluminum test object with the RVG 32000 it proved possible to detect defects as small as 0.1 mm in 7.0 mm of aluminum, and as small as 0.2 mm through up to 3.0 mm of radiopaque composite resin tooth restorative material (5) or up to 0.3 mm of steel orthodontic bands (6). Studies using extracted teeth with simulated caries showed that E-speed film and the RVG-S are similar in the ability to display simulated caries in the absence of orthodontic bands, with the VIXA trailing in this ability due to a high level of electronic noise. In the presence of orthodontic bands, however, the RVG-S with steep gradient enhancement and a shortened contrast scale (the X-function) outperformed all other modalities tested for detection of simulated caries beneath the bands (7).

DIGITIZATION OF ANALOG RADIOGRAPHS: With the EScan Dental Link Software (Santa Rosa, California) combined with the XRS flatbed scanner (Torrance, California) it is possible to digitize analog film and to provide the same digital image processing capabilities found with CCD-based devices. The characteristics of the scanned image depend upon the selected scanning parameters such as the number of dots per inch (dpi) spatial resolution, and the dynamic range used.

DISCUSSION: CCD-based intraoral radiographic devices provide no additional scales of gray and a reduced resolution when compared to film so why are they successful? The answer is simple, the image is immediate and there are many operative procedures in dentistry where

this immediacy is a great advantage. Additionally, more is not always better. The question should not be what spatial resolution can be achieved, but rather what is needed for dental diagnosis and treatment. It is unlikely that a difference of 100 micrometers would have any clinical significance; hence, the CCD devices are equal clinically with film regarding spatial resolution. Concerning contrast resolution, the CCD systems are all 8 bit restricting the gray levels to 256 of which 64 are usually displayed on the monitor. This contrast resolution appears to be sufficient for detection of dental lesions, and unlike film it is possible to effect contrast stretching, windowing and frequency adjustments. The latter is possible with film, but requires the extra step digitization. CCD systems mean that it is also possible to eliminate the darkroom, film supplies, and processing solution purchases and disposal. Finally, the sensor being thicker is not subject to bending which can effect distortion, and is also much more comfortable for patients when placed in the mouth.

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Integrating a Radiology Information System with a Commercially-Available Computed Radiology Apparatus: An Example of an Interactive Gateway

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ABSTRACT

We have developed a method to automatically transfer patients' demographic data from a Radiology Information System (RIS) into a computed radiography (CR) system by using inexpensive personal computer hardware and software. An IBM-compatible personal computer (PC) was configured with inexpensive, commercially-available programmable telecommunications software. This interactive gateway eliminates the need for redundant data entry (compared to entering data once on the RIS and again on the standalone CR system), and thus also decreases errors in the labeling of images.

INTRODUCTION

The need for rapid, convenient, and accurate transfer of demographic data within the radiology department has been well documented,¹⁻² and the development of the RIS has provided most departments with an excellent infrastructure for adding additional capability. As picture archiving and communication systems were developed, the need for appropriate interfaces was recognized early, and most systems have at least some ability to receive information from the RIS.³⁻¹¹ Unfortunately, little has been written about the need to interface a computed radiography device to a RIS.¹²⁻¹³ although a good method of transferring this information can do much to enhance both patient care and department efficiency.

Although these techniques could also be applied to other devices such as CT and MRI scanners, the large amount of additional data which must be entered before initiating a scan makes the patient demographics a very small factor. With CR, however, the patient demographics represent the majority of the information which is entered, the number of examinations per day can be large, and thus an RIS interface represents a substantial improvement in efficiency.

We have used computed radiography for all portable images at our medical center for five years,¹⁴ and have been forced to enter demographic information for each patient, and for each subsequent examination. Although we have had a Radiology

Information System (RIS) installed for nine years, we have been unable to transfer this demographic information from one computer system to another, due to the lack of an appropriate provision for input on the computed radiography device. In late 1993, we purchased a replacement CR device, and were unable to find a vendor which provided adequate interface to our RIS. Although an RIS interface computer system is available from the vendor, there is no mechanism available for interfacing to it without customization of our RIS.

METHODS AND MATERIALS

We use inexpensive personal computer (PC) software which can be programmed to interface the two systems. This software transforms a personal computer into a RIS-compatible terminal which communicates with the CR device and maintains a local data base for periods when the RIS is inoperative. Connectivity with both the RIS and the CR device is via serial (RS-232) methods. The PC-based software supports parallel processing within the context of telecommunications. That is, one or more simultaneous automated telecommunication sessions can be running. Each session "owns" one serial port on the PC, and a program (script) can be executing within each session. Intersession messages can be passed among two or more simultaneously executing programs. In our implementation, there are two concurrent sessions. One session (the terminal emulation session) is visible to the user, making the PC appear to be an RIS terminal. The other session operates in the background, communicating with the CR device.

The software recognizes when a patient's data is displayed on the screen. If the appropriate "hot key" is struck, the patient's data is captured, formatted, and (following confirmation by the user) instantly transferred to the CR device. At our site, CR examinations are not scheduled on the RIS until after they are performed (e.g., "post-scheduling"). When the technologist is ready to process the CR film, he or she uses the PC to interact with the RIS and post-schedules the examination. When the patient's data is displayed on the screen, it is immediately transferred to the CR device via the hot-key method. This provides the following benefits: (1) eliminates redundant data entry, (2) data on the film exactly matches data in the RIS, and (3) the examination identification number is transferred to the film (a feature not available with the film-labeling device included by the vendor with our CR system).

The CR device is an AC-2 computed radiography plate reader provided by Fuji Medical Systems (Stamford, CT). Our RIS is IDXrad (IDX Inc, Burlington, VT). Our interface is implemented on a 386-33MHz PC computer system running MS-DOS 6.2. The computer contained two RS-232 communication ports. One is connected to the RIS computer, and the other to the CR device. Crosstalk Mark IV telecommunication software (Digital Communication Associates, Inc. (DCA) Alpharetta, GA) includes a powerful programming language much like "C". Programs written in this language provide appropriate data exchange between the

RIS and the CR device. A local database of the most recent 150 patients is maintained with Crosstalk. This allows us to continue to use the interface computer during times when the RIS is not operational because previous demographic information is locally available to the radiologic technologist. The technologist can always enter demographic data into a "pop-up" form when the RIS is inoperative and no prior data is locally available for a patient.

DISCUSSION

This method has both advantages and disadvantages. Crosstalk can emulate virtually all industry-standard terminals. Thus, by modifying only a few lines of source code, this system can be adapted to virtually any RIS which uses standard serial communications, TCP/IP, IBM 3270, or LAT protocols. Once the system is programmed to recognize the germane screens of a particular RIS, it can be installed in a few minutes. Because the keystrokes required to run the system are very similar (if not identical) to those of dedicated RIS terminals, technologists require very little training, although they must learn about the special key used to invoke the transfer of information to the CR device. A disadvantage is that if the RIS vendor substantially changes the appearance of screens which display a patient's data, the Crosstalk software must also be modified to recognize this. In our experience, this is a very uncommon occurrence.

As we began to use this system, we discovered an interesting anomaly. The CR computer will not accept information until the CR plate is inserted into the reader, and the door is closed. Any attempt to transmit information prematurely is answered with a status message that the device is not ready. Thus, the technologist must either insert the plate first or receive an error message on the screen. Although this aspect of the CR device's protocol does not pose a problem to system operation, it was an unexpected discovery. The system has been easy to use and, thus far, reliable. The amount of interaction required is less than with our previous CR configuration. The accuracy of the demographic data printed on the film and stored in the digital CR database is improved.

If the examination is already scheduled in the RIS, a bar-code reader can be used to read the examination card which was printed after scheduling. This, and the current time of day, automatically records the completion of the examination in the RIS and transmits the full information set to the CR. The use of such a script makes the system extremely fast and convenient in radiology departments which do "preschedule" (rather than post-schedule) their examinations on the RIS, even if just a few minutes before they are actually performed.

Although an interface between a RIS and a CR system is required for efficient work flow in the radiology department, manufacturers have not provided adequate capability for the vast majority of hospital environments. The large number of RIS configurations makes the typical fixed-program interfaces unworkable for most sites.

Our method, which uses a commercially available, programmable communications product, offers a straightforward way to accomplish RIS-CR integration. The program we have developed can be easily adapted to accommodate updates to our RIS, and can also be adapted to a different vendor's RIS. Information about the availability of the scripting software is available from the authors.

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SESSION 19

PACS Integration

Chair: Carl E. Ravin

Migration of Multiple Mini-PACS Installations to Integrated PACS

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1. INTRODUCTION

The Department of Radiology at the University of Florida has implemented several Mini-PACS and local Teleradiology systems over the past five years. The good news is that the users, physicians, technologists, and clerks, have become comfortable with the systems and use them in their daily routine. The bad news is that they have had a taste of the future and expect more functionality and higher performance. Specifically, retrieval time from mass storage devices is too slow to be used routinely when time is important, and multiple archives managed by distributed heterogeneous databases do not have a common user interface and query language. Physicians in referring clinics would like to see images attached to electronic diagnostic reports, while Radiologists would like initial window and levels set on images before first time viewing on workstations and need accurate and complete information about the patient and study in the PACS database.

In this paper, we present an analysis of the current systems along with the design for the new integrated PACS incorporating each of our current systems with an expansion path that will continue to offer high performance access to all radiology images along with the infrastructure required for accurate and complete data storage.

II. REQUIREMENTS ANALYSIS

Figure 1 illustrates the current PACS systems implemented at the University of Florida. CT - MRI PACS uses a Kodak solution with short term image storage on magnetic disks on Mig3, the acquisition computer receiving images from CT and MR equipment. Permanent storage is on an optical platter jukebox with a 1TByte + capacity. Mig1, the computer managing the archive, has 8.3GBytes of magnetic "working store" for faster retrievals of recent studies. With an average acquisition rate of 1.3GBytes / day from CT and MR, this should hold images for approximately six days. However, since this space is also shared with images retrieved from the jukebox for comparison, requiring about one third of the space, and the disks are purged at the end of each day to make room for the next day's workload, only three days of current studies on average are available for fast retrieval from magnetic disk. For example, when the system is lightly loaded, it typically takes 40 minutes to move 40 MBytes from the optical jukebox to a UNIX workstation and 7.5 minutes to move the same 40MBytes from the magnetic working store to the UNIX workstation. Under heavy load, the performance degrades rapidly. CT and MRI studies are routed to the

appropriate workstation (neuroradiology, abdominal radiology, pediatric radiology, or musculoskeletal radiology) and to the archive. All four destinations compete for retrievals of old, comparison studies from the jukebox. Because all requests for retrievals are queued in order of receipt, regardless of the location of the images, requests for images from the working store can take as long to return as from the jukebox if they follow jukebox retrieve requests.¹⁻⁷

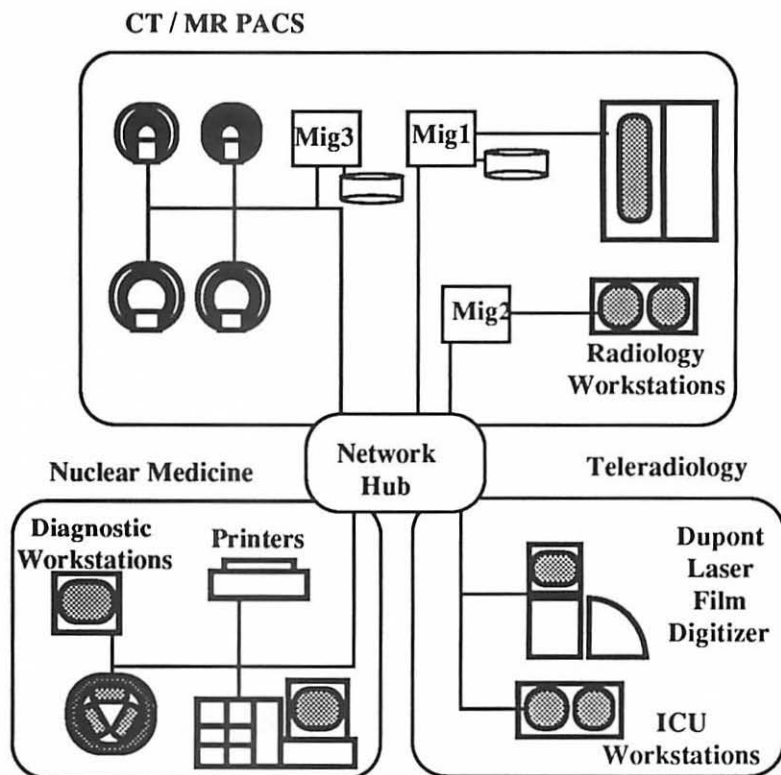


Figure 1: University of Florida Mini-PACS

A nuclear medicine PACS was developed in-house based on Trionix acquisition equipment. A 40 GByte magneto-optical jukebox and a 6 GByte magnetic working store archive images from six gamma cameras and serve the images to 8 Sun SPARCstation workstations. With an average of 6:1 compression, the magnetic store can handle up to 15 months of studies while the jukebox is projected to hold 8 - 9 years. This division is filmless, although printing is available on color paper printers. The database and archive serve only nuclear medicine requests and are only available to nuclear medicine users. There are increasing requests for access to some of the images by other divisions in radiology. For example, musculoskeletal radiologists would like to see nuclear medicine bone scans. Although we have implemented an interfle to ACR-NEMA vs. 2 interface, it is not readily available for clinical use.⁸

A Dupont based Clinical Review System (CRS) consisting of a digitizer and five Intensive Care Unit (ICU) display stations has been in use for nearly six years to send electronic versions of portable images to the ICUs while retaining the films in

radiology for diagnostic interpretation.^{9,10} Digitized images are not archived. We have implemented a Dupont - ACR-NEMA vs. 2 interface, but are unwilling to begin routing images to workstations in radiology and to an archive until we have solved the image retrieval issue. We believe that portable images may not have to be printed and that if we replace the digitizer with Computed Radiography (CR), that we can eliminate film for this function while improving image quality for portables displayed in ICU.¹¹

Problems that are common among all three areas are associated with data entry on the acquisition consoles. When humans are asked to enter a patient name and medical record number, errors are bound to occur. It is difficult to enforce a standard way to enter a name with the choices of upper and lower case, comma, spaces, middle initial or name, etc. Digits are easily transposed in a medical record number. Acquisition consoles vary between vendors with different fields available for data. In order to accurately route images, we need to know a precise procedure description and date of birth (pediatric vs. adult). In order to use a preset window and level so the physicians can see a reasonable image when first viewing it, we need to know the modality and a procedure description. These problems can be solved by using an RIS - PACS interface to either enter the information on the console or to verify and complete the information after the study is done, before it's archived and routed.¹²

One of our requirements was to use as much of the existing hardware and software as possible to contain costs. The integrated system was designed to provide a more comprehensive infrastructure for expanding PACS. Built in modularity and reusable software allows us to expand the system using the same basic functions for all acquisition, routing, user interfaces, and archives.

III. INTEGRATED PACS

Figure 2 illustrates the overall design for the integrated solution which is based on a central database and distributed archives. We investigated the potential of a large central archive and found them to be either too slow with the contention we expect from multiple sites, or too expensive. Smaller magneto-optical jukeboxes (~200GBytes) are relatively inexpensive and can be placed logically close to the primary users. In our organ system based department, neuro studies from the entire department are read in the neuro reading room, orthopedic cases are read in the musculoskeletal reading room, etc. We have identified the need for six archives when the time comes to convert to a totally digital department, serving the areas of musculoskeletal, chest, neuro, abdominal, mammography and nuclear medicine. The chest archive will also hold pediatric studies and portables, the abdominal archive will include visceral angiography and ultrasound, and the neuro archive will include neuro angiography. Other studies that are not classified to one of the predefined archives will be assigned to an archive according to where the diagnostic interpretation takes place.

Image flow is as follows. Images are acquired and routed to their destination workstations or workstation server with enough magnetic storage for 3 days of current and comparison studies. In addition, they are routed to their short term archive, a magneto-optical jukebox, where they are stored using lossless compression. The short term archives are sized to supply a six month capacity. Each acquisition computer has enough magnetic disk to allow work to continue in the case of archive or network downtime. Each magneto-optical jukebox has an 8 mm helical scan tape that backs up

all studies chronologically as a full backup to be used in case of catastrophic failure. Tape capacity is between 5GBytes and 25GBytes depending on data compressibility with a tape cost of about \$15.00 each. Tapes will be stored indefinitely.

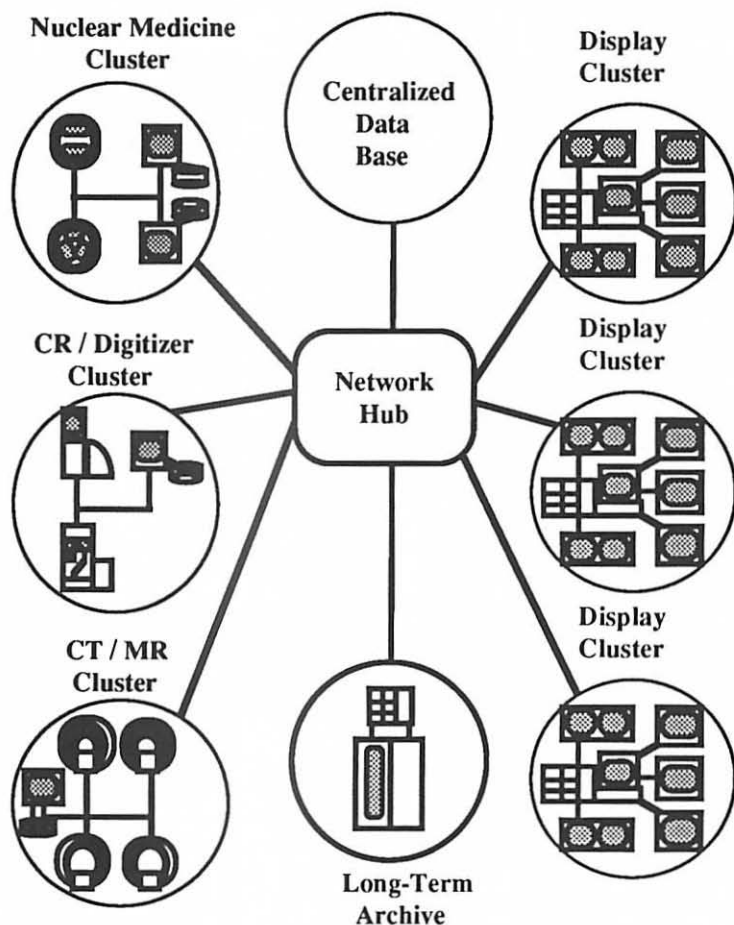


Figure 2: New PACS architecture

When the short term archives reach a high percentage of their capacity, images will be grouped by patient and will be moved to the long term store (current optical jukebox), using lossy compression with which we are anticipating a 10:1 compression ratio. Although the required volume will exceed the capacity of the optical jukebox, it will be placed in a hospital computer room that is manned 24 hours / day with personnel who can load a disk on demand.

The central database is fully redundant on two computers located in different buildings. One database is used routinely with the software switching to the other if needed. Oracle was chosen for the Database Management System (DBMS). As an image is acquired and routed through the system, each location is responsible for updating the database with the image location. An image may exist in several places, one or more workstations, a short term archive, and the long term archive, however,

the location of the study is invisible to the user. A request for the image will result in the image being moved from the fastest location. In the case of nuclear medicine where studies are not stored in the DICOM format used in the rest of radiology, when a study is requested, it is converted to DICOM as it is retrieved. Although it is unlikely that radiology images will be needed in nuclear medicine, a conversion program has been written for research use that can be adapted for clinical use if required.

The RIS / PACS interface was developed through a cooperative effort between Radiology and the Department of Information Services at Shands Hospital who manage the RIS. An RS-232 interface was our only option. A server process communicates over the RS-232 line to the RIS issuing queries and receiving responses. Client software is attached to acquisition computers that allows barcode entry of accession numbers and management of the resulting data. Clients communicate with the server over TCP/IP.¹² A technologist uses the barcode reader to officially start the examination, then performs the examination as usual. When the images are transferred to PACS, it is simple to match the resulting data to the images, correcting the format of the name and adding the additional procedure information needed for routing and display. All images are reported to the central database, and routing is attempted, but if a study cannot be electronically matched to an RIS entry, it is marked "unverified" until the system administrator or file room clerk can manually match RIS data to the study. When acquisition manufacturers allow direct input of data to the operator's console, we hope to use the barcode to enter all the required data prior to beginning the study.

Since the RIS and PACS were developed independently, there are no common keys that allow us to link images and reports. The RIS / PACS interface provides us with the information needed to identify common keys for future integration of images and reports.

The integrated PACS designed for the University of Florida is now being implemented in-house using industry standards when possible. Oracle and SQL are used to store archive information, Motif is used to develop user interfaces, and TCP/IP or FDDI are used for network protocols. Images are stored in the ACR-NEMA or DICOM image format. If a new RIS system is purchased, the only module of the RIS/PACS interface that will need to be replaced is the one between the server and the RIS system. Client and server software over TCP/IP will remain the same. Archives can be replicated and deployed where needed to optimize retrieval. We believe this design is simple, inexpensive to build, and easy to maintain. It is essential that an integrated, total PACS solution includes the infrastructure provided by the RIS / PACS interface and a central database.

SUMMARY

After several years of working on PACS related issues solving individual problems as required, we realize the need to integrate the current systems into a single, comprehensive PACS. The users of the systems have requested a higher level of performance and functionality with faster access to any digital image stored on an archive. We also need to archive additional images, such as ICU portable examinations, and present them on softcopy without printing film. Until we can provide a solid, reliable infrastructure and a fast archive solution, we cannot proceed with expansion plans.

Our solution is based on standard hardware and software, it incorporates existing equipment, and is modular for easy maintenance and upgrades. The distributed archives with a central database provides all users with images from any location, while optimizing the speed of retrieval from the archive most likely used by a workstation. The RIS / PACS interface provides us with accurate, complete information needed to route images, preset windows and levels, validate patient information, and provide the links necessary to integrate images and diagnostic reports.

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Second Generation Folder Manager for PACS

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INTRODUCTION

Picture Archiving and Communication Systems (PACS) have been developed and implemented at a number of institutions in recent years. These systems have received mixed acceptance by radiologists and other physicians primarily due to the lack of "user-friendly" features at the physician's workstation. A major cause of the poor user interface has been poorly-designed software, often written by engineers with little clinical knowledge and limited input from radiologists. These workstations often offer many features that are rarely used, yet do not allow the physicians to perform their tasks with ease or speed. A software package called the Folder Manager (FM), which is designed to control a PACS, attempts to solve some of these problems.

FM manages the acquisition, transmission, storage, and presentation of sets of medical images. It was first conceived and implemented at the University of Pennsylvania.^{1,2,3} The earlier version provided for the interface to the Radiology Information System (RIS) in order to receive basic patient demographic data, and examination data from scheduling and notification of exam completion. The primary reason for accessing exam scheduling data was to provide for pre-fetching of previous images from the archive for comparison purposes. This early FM also controlled the image display sequence for digitized portable chest x-rays in the Medical Intensive Care Unit (ICU). Pre-fetching and auto-sequencing were utilized in order to speed physician interaction with the workstation.^{4,5}

METHODS

The architecture of the second generation FM is a distributed software suite with modules residing in computers at each network node^{6,7,8}. The FM directs the actions of the PACS controller. The second generation FM provides a variety of additional features including archive / platter

management, network management, and display / server management. In addition to pre-fetching previously-stored images for comparison purposes, the archive manager handles the distribution of images on the optical storage devices and on the network. Use of the platters must be balanced to provide optimal image read / write activity, minimal platter contention, and optimal archiving. In the UCSF PACS, images from inpatients are stored on magnetic media and erasable optical media until after discharge, when the images are consolidated onto one WORM (write once read many) optical platter. For outpatients, different aging criteria are used based on examination type.

The pre-fetching and routing processes use a table of parameters which can be modified by privileged users when appropriate. This table provides the logic which determines the set of images to be sent and selects the appropriate destination display or working storage (magnetic storage at the central archive, at a display server which handles a group of workstations, or on the workstation itself). A sample of the pre-fetching table is provided in TABLE I.

TABLE I. LOGIC TABLE FOR PRE-FETCHING ALGORITHM

New Exam Type	Previous Exam Types	Max Age Limit	Max No Limit	Special
Ch 2 views	Abd, Ch CT, T sp	7	3	Oldest
MRI Pelvis	MRI or CT Abd, Abd, Pelv US, Hystero	7	4	
Mammo	Br Bx, Br US, MRI	Life	3	Oldest

The maximum age limit and number limits are in years preceding new exam. The previous exam types are in addition to the similar exam list in IDXrad (IDX Corp., Burlington, VT). The term "oldest" in the special column refers to the addition of the oldest image / sequence available in the archive for the patient similar to the new exam.

The network manager module works closely with the archive manager in order to determine the appropriate destination for images based on examination type, location acquired, and other special parameters (See TABLE II). It also has the tasks of queuing images when workstations are not available (i.e. network or computer failure), controlling the RIS interface, determining the location of images in the distributed database, and routing traffic in the network to minimize contention and provide for priority handling.

TABLE II. LOGIC TABLE FOR ROUTING ALGORITHM

Event	Exam Type	Condition	Destination
Exam Comp	Ch	Tech Mod = Port	Chest High Res
Admission	Ch		MICU
Exam Comp	Ch CT, MR	Hosp=MtZ	Chest Low Res
Exam Sched	Head, Spine		Neuro MtZ
	CT, MR	MD=Neurosurg	Neurosurg Office
Dictated	All		

The event type is determined by IDXrad communication message. The high-res workstation is 2K x 2K, 12 bits, while low-res is 1K x 1K, 12 bits. Admission for the MICU means admission to the unit, which could be a transfer from another inpatient site. The Neuro MtZ workstation is in the Moffitt Hospital, but the images come from the remote site at Mt. Zion Hospital. The previous comparison images are sent to the display when the new exam is scheduled (links to the pre-fetch table). Note that, in the last example, images are not sent to the Neurosurgeon's office until after they have been dictated (verbal report available with images).

The display / server controller provides for the sequencing of images based on examination type, comparison images available, physician preferences, and workstation configuration. Selection of appropriate images for comparison is also provided by the display controller. Pre-set window and brightness levels are also established by this module (See TABLE III). User preferences are recorded in order to adjust the pre-sets of future images for each physician. Coordination with consultation reports is another function provided. The digitized spoken dictation is provided with the associated images until the preliminary report has been transcribed. The finalized, "signed" report replaces the preliminary report when available. Reports are always presented with the images from the time of dictation.

The use of automated sequencing with previous comparison images and pre-set window and level facilitates the physician interaction with the workstation by eliminating unnecessary manipulation. Simply by pressing the mouse button for the "next image / next sequence", the physician can be assured of viewing all appropriate images in a logical pre-defined order without worrying about choosing images from directories or lists. By avoiding changes in window and level except for unusual circumstances, the physician saves considerable time as well as having increased confidence because of more consistency in image presentation. Physician preferences, established in the Physician Dictionary, determines user-based options such as whether the workstation presents images in multi-image per screen format or in large image with synchronized page-flip feature (similar anatomical sections for two different sequences, each on one monitor with the ability to move through the stacks of both sets in tandem.).

TABLE III. LOGIC TABLE FOR IMAGE PRESENTATION SEQUENCE WITH TWO MONITORS

Exam Type	Monitor 1	Win/Lev	Monitor2	Win/Lev
Ch 2 views Ch CT wCntrst	PA	Ch1	LAT	Ch2
	PA	Ch1	PA-1:n	Ch1
	LAT	Ch2	LAT-1:n	Ch2
	Seq-NC	Soft Tis	Seq-NC	Lung
	Seq-C	Soft Tis	Seq-C	Lung
	Seq-NC	Soft Tis	Seq-NC-1:n	Soft Tis
	Seq-C	Soft Tis	Seq-C-1:n	Soft Tis
	Seq-NC	Lung	Seq-NC-1:n	Lung
	Seq-C	Lung	Seq-C-1:n	Lung

For each exam type, each line in the above is taken sequentially. This table is specific for a two monitor workstation. Different tables exist for other numbers of monitors based on the destination (in the Routing Table).

PA-1:n means the sequence of the most recent previous PA view through the nth oldest previous PA view. n is determined by the maximum number set in the Pre-fetch Table. Each time the "Next image/sequence" button is pressed by clicking the mouse the next set/series of images appears on the monitors. If the images are greater than what can be displayed at one time, the other images are queued or loaded into off-screen display memory for scrolling or paging. The operator can also go backwards step by step, or jump to a menu to customize the grouping.

Moving on to the next exam or patient is also a simple mouse selection. The Window/level settings are established in another table for each exam/view type/sequence. These values are modified by user preferences either in the physician dictionary or by analysis of patterns of use.

SUMMARY

Advantages of the second generation folder manager include faster image access at the workstation, reduced image manipulation by the physician, reduced likelihood of missing image information, and improved likelihood of having desired images on-line. The FM assures that available reports are displayed with the images. The cost for PACS is reduced due to the decreased need for high-speed networks, decreased storage requirements, and fewer special workstations. Physician acceptance is improved because of the automated display functions.

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Medical Experience with an Ultrasound PACS at the VA Medical Center, West Los Angeles

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1. INTRODUCTION

We have installed a mini-PACS for the ultrasound department at the Veterans Affairs Medical Center, West Los Angeles (A UCLA affiliated hospital). The key component of this ultrasound mini-PACS is a medical gateway providing acquisition service, network spooling functions, and patient management services. This is performed with a commercial product from AGFA: the MG1000. The MG1000 is a VME-based medical gateway that supports on-line analog video acquisition, and digital image network transmission capability. The MG1000 accepts low line analog video data, i.e., image sizes up to 880 pixels X 480 lines with 8 bits per pixel. The MG1000 is primarily used as a concentrator hub for acquisition in ultrasound departmental networks.

In our department, three ultrasound rooms are connected via the MG1000 to an archiving and display station. The ultrasound rooms have the following equipment: Toshiba SSA-270A, ATL UM9-HDI, and Acuson XP128. Analog images are formatted into DICOM 3.0 compliant folders and sent over ethernet to the archiving station (AS1000). The AS1000 is used for archiving, review, and also for reprinting past studies. The AS1000 has a 10 Gigabyte optical jukebox which is serially connected to the AS1000.

We will report on: our clinical experience with this PACS and the advantages of being able to use standard film sizes versus the small ultrasound film sizes. The advantages of creating teaching files, being able to retrieve image data for referring physicians, and having the capability of multi-modality review will also be discussed.

2. THE IMPAX™ PRODUCT LINE

The initial design of our PACS is based on commercially available components from AGFA (1, 2, 3, 4). AGFA has a wide array of commercially available PACS-subsystems. Their product line is called "IMPAX™", and consists of image acquisition units, image archive units, and image reviewing stations. The product line includes: medical gateways (MG1000), archive stations (AS1000, AS3000) and review stations (RS1000). These different components will be reviewed.

2.1 Medical Gateways

The MG1000 supports up to 6 monochrome analog video acquisitions, removable disk sub-systems (for portable ultrasound exams), and digital image-networking capability (5, 6, 7). The MG1000 only accepts low-line analog video data i.e., image sizes up to 880 pixels by 484 lines with 8 bits per pixel (i.e. up to 0.426 MByte/image). As a result, the MG1000 is primarily used as a concentrator or hub for data acquisition in imaging networks used in small departments, such as ultrasound. Each MG1000 can be configured in many ways to meet the specific requirements.

In addition to analog video capture, data can also be imported into MG1000 via removable disk cartridges (used for portable ultrasounds) or, as in the case at UCLA VA Wadsworth, via write-many-read-many (WORM) erasable disks. By teaming the digital storage path on one of the ultrasound systems (the ATL UM9-HDI) onto optical disks and the digital print capabilities of the MG1000, via fiber optic links to the laser printer, it is possible to provide a completely digital path for both soft and hard copy output devices.

The MG1000 is VME-based and has a two CPU architecture controlling acquisition, network access and SCSI bus access. Still framed images can be acquired at a sustained rate of approximately three seconds per image for a fully loaded system. However, the 100 MB local hard disk has a capacity to hold three hundred digitized video images, which is adequate due to the multi-tasking systems approach taken in the MG1000, i.e. printing and network activity occur simultaneously. Both color and monochrome image data may be acquired.

2.2 Archive Stations

Display, archival, and manipulation of image folders is reserved for the workstation based AS1000 IMPAX™ products (AS refers to archive station). Each archiving stations comes with a standard color monitor capable of 1,280 x 1,024 x 8 bit display.

The AS1000 is a SUN Microsystems Corporation (SMC) SPARCstation-2 computer with two 424 MB internal drive. The platforms have 48 MB of RAM, two internal hard drives, and a GX+ frame buffer capable of supporting displays up to 1600 pixels by 1280 lines by 8 bits per pixel. The internal hard disks provide very fast images for a period during which maximum recall is performed, usually from 3 to 5 days.

Medium-term archiving is provided in a juke-box using erasable disks. Each disk is reusable, i.e. WORM, and after formatting can store 1 GB of data. Ten to twenty such disks are loaded into a 10 or 20 GB multi-function optical jukebox that is attached to the SCSI bus of the AS1000. A lossless compression technique, using Lempel-Ziv-Welch (LZW) coding, is currently employed. With 3:1 lossless compression ratios, approximately 100,000 ultrasound images can be stored in the jukebox offering a 6 to 9 month archiving capacity. Due to the overhead involved in compression / store and retrieve / decompression cycles, access times average approximately four seconds per image.

The AS1000 performs optical character recognition (OCR) on incoming folders transmitted from the MG1000. Pre-defined regions of the first image from the received folder are examined for patient demographic information. These regions are defined in configuration files that are specific

to each ultrasound acquisition device. Each region is evaluated for a string of characters which is identified by the changes in intensity (gray level) of the characters with respect to the background. Characters are classified based on the Least Mean Square Error (LMSE) of heuristics extracted from the observed characters and heuristics calculated from training data i.e. template data. Usually, patient name, patient id and procedure are extracted from the image to be used for data management on the AS1000.

2.3 Review Stations

The review stations are based on SUN SPARC LX computers. The RS1000 is a multi-modality review station which can be placed anywhere on the network. It uses a standard color monitor with the option of dual monitors. The review stations are used for reviewing patient exams from the electronic archive of the optical jukebox. Images can be automatically transmitted from an archive station to a review station at the time of patient scanning, which means that the images are instantaneously ready to view at the desired location. Exam folders may be printed by retransmitting the folder to a medical gateway for print spooling. Or, they may be displayed for review and window/level adjustments. Or, critical images of several exam folders may be combined to form teaching folders, which in turn can be transmitted for printing. Review stations provide the same functionality as the archive stations aside from archive and data base management operations.

3. ULTRASOUND MINI-PACS ANALYSIS

3.1 Description of System

The initial configuration of the ultrasound mini-PACS at the VA Medical Center, West Los Angeles consists of an MG1000 medical gateway and an AS1000 archive and is shown in Fig 1.

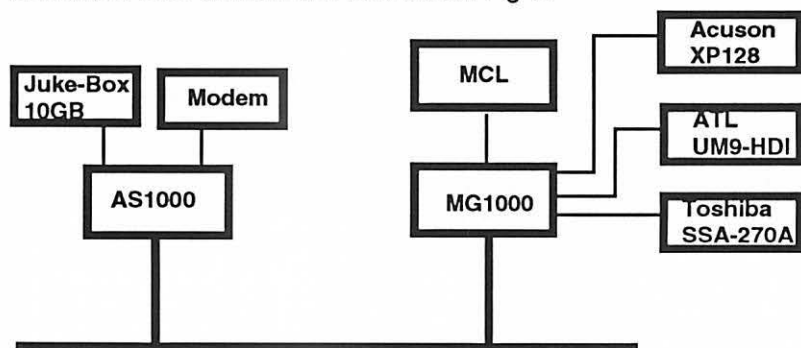


Fig 1: Ultrasound mini-PACS at VAMC, West LA

At the VA Medical Center, the MG1000 is configured as a universal gateway providing acquisition services, network spooling functions, and print management services. The archive contains a jukebox with 10 GByte storage. A color monitor is used for display. A laser printer (MCL) and three

ultrasound rooms are connected to the MG1000. The ultrasound equipment used is: A TOSHIBA SSA-270A, a ATL UM9-HDI, and a ACUSON XP128. The MG1000 acquires images of various sizes in order to maximize image quality for both soft and hard copies. All ultrasound images are usually digitized at 640 x 480 by 8 bits (0.293 MByte/image), typical RS-170 signals. However, video data from the ACUSON machine are digitized at 752 x 480 x 8 bits. Transmission to the AS 1000 is TCP/IP over ethernet. All image folders are compliant with ACR-NEMA 2.0 and upgrade to the DICOM 3.0 standard is underway (8).

Similar to most ultrasound departments, we used to use 8 x 10 inch single emulsion CRT films with 6 images per film (9) Since implementing the mini-PACS, we have switched to 14 x 17 inch laser-quality films with 15 images per sheet (10). This greatly improves handling of the film by radiologists. The new film format is more compatible with other films being used for comparison studies, e.g. CT or MRI. Film storage has also become more convenient as we no longer need special small ultrasound film jackets.

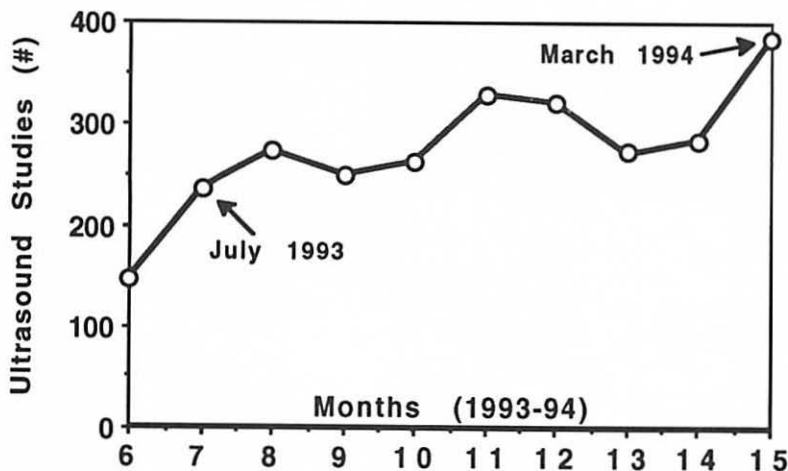


Fig 2: Number (#) of Ultrasound Studies Archived at VAMC, West Los Angeles

3.2 Average Workload

Over the last nine months the average number of studies was 289 per month, with an average of 31 ± 19 images per study. The number of studies per month over a nine month period was relatively constant (Figure 2) as was the number of images per study (Figure 3). The amount of digital storage required by these ultrasound studies is shown in Figure 4. Approximately 80% of the optical disk storage in the jukebox (approx. 8 Gigabytes) was needed for a nine month period. The lesser amount of storage needed in June reflects the fact that the system went into operation in mid June.

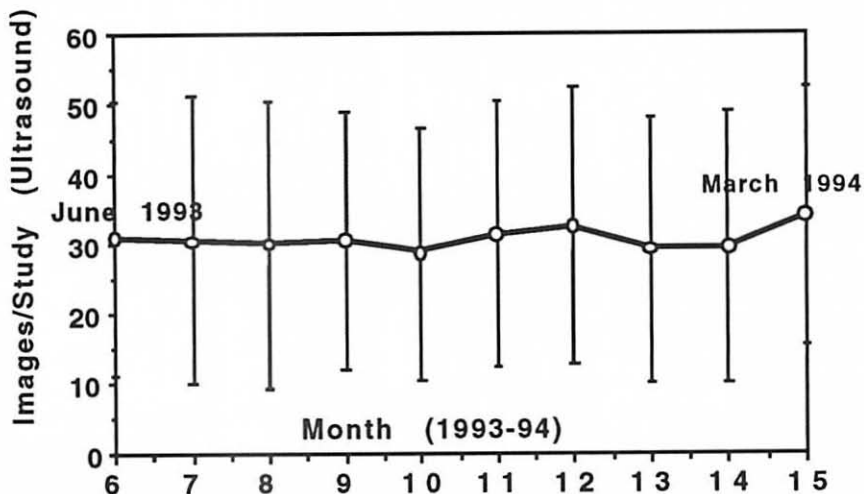


Fig 3- Images per Ultrasound Study
(error bars = one standard deviation)

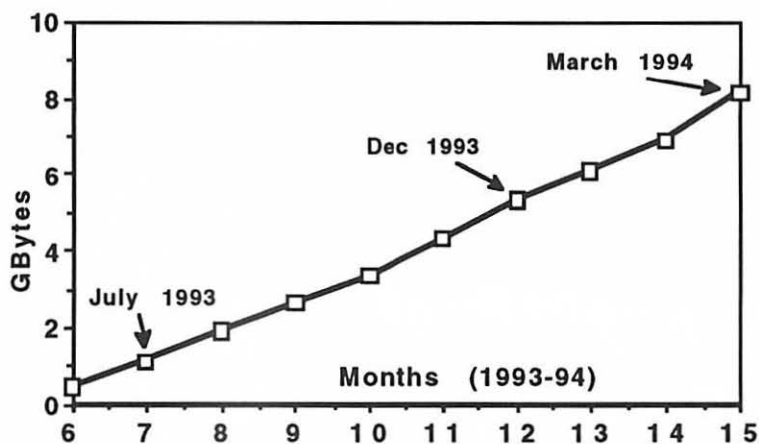


Fig 4- Volume of Ultrasound Image Data
Archived at VAMC, West Los Angeles

The presence of the MG1000 is totally transparent to the users. It replaces manual labor (handling film) and automates the multiplexing and filming of studies from different ultrasound rooms. Neither the technologist nor the radiologist are made aware of the PACS system, which is one of the greatest features of the AGFA-IMPAX™ implementation. The only change in the operation of the ultrasound instruments is the replacement of the normal "print" button with a custom made control to handle printing.

We also reviewed the retrieval rates with the mini-PACS and its utilization. Over the last 9 months, approximately 104 exams out of the 2796 exams archived (3.72%) were retrieved and reprinted (11). Reasons for

retrieval included: lost films, requests for duplicate copies from referring doctors, films for teaching files, or simply whenever reprinting appeared easier than locating the original films.

4. COST IMPACT

Most interesting and important is the effect that the mini-PACS system has had on the cost of operating the ultrasound department (10, 12, 13). By having this system available, we have eliminated the need for a half time technologist (or a full-time film clerk). Prior to the PACS system, many hours per day were spent in the dark room developing films, and handling the films in between the different ultrasound rooms and the dark room.

There was however, also a negative cost impact. A review of the cost of film and digital archiving over the last 9 months showed that by switching from small film formats to large formats, the cost of film has increased by 14% due mostly to the improvement in quality of film (laser quality vs. CRT quality). The usage of an optical disk backup storage devices added an additional 19% cost. This comes to a total of 33% increment in cost for storing the digitized images. The daily increment in cost, and its change over a 9 month period, are shown in Figure 5.

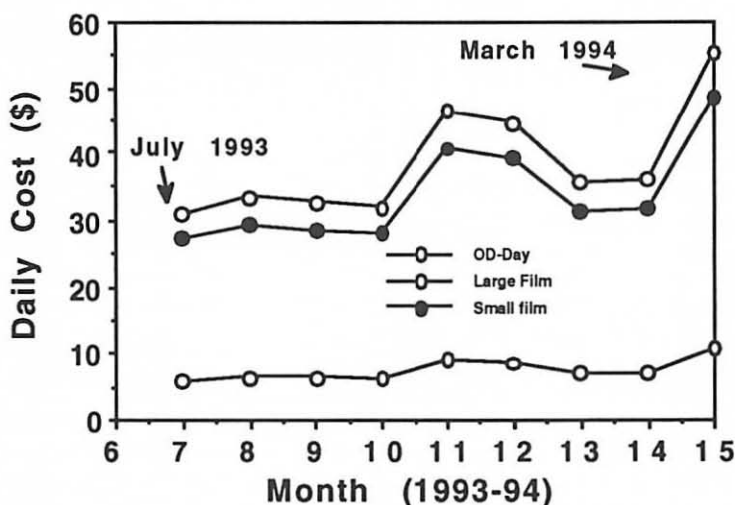


Fig 5 - Daily cost figures for combined film storage and digital storage (OD= optical disc)

In order to evaluate the trade-off between reduction in labor cost, and increase in hardware and image storage cost, we did the following simplistic calculations. An approximate purchase price for the MG1000 and AS1000 of \$25,000 and \$75,000 respectively (total of \$100,000), and a \$60,000 a year salary for a highly qualified and trained ultrasound technologist are assumed. Assuming a 100% savings in labor cost and an additional cost of \$508/ month in storage, the break even point is 24 months. This break even point is somewhat artificial as it totally neglects the increased convenience and operator friendliness and other benefits of the system.

5. EFFECT ON DEPARTMENTAL OPERATION

The impact of the mini-PACS has been significant. Most importantly, as stated above, it is transparent to the user. The large film format is convenient and compatible with other film formats. We are now able to reprint any ultrasound study upon request. It facilitates review of old studies without needing to wait for retrieval studies from the file room. It allows annotation of studies for research and teaching purposes and it potentially will allow communication with all departments within the hospital.

6. CONCLUSION AND DISCUSSION

In conclusion this mini-PACS allowed a much better utilization of personal resources in the ultrasound department. There is however a slight increase in direct cost for storage. In the future it will allow full communication with the full blown PACS system, and RIS/HIS systems (13).

7. ACKNOWLEDGMENTS

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Strategies for the Clinical Evaluation of PACS: Experience with Experimental Design in a Medical Intensive Care Unit

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Technology evaluation typically includes estimates of safety, efficacy, and cost [1]. Safety and cost will not be considered here. The main issue is the definition and measurement of the efficacy of picture archiving and communication systems (PACS).

Efficacy is formally defined as "the probability of benefit to individuals in a defined population from a medical technology applied for a given medical problem under ideal conditions of use"[2]. The term effectiveness is applied when the conditions are not ideal and reflect typical medical practice. Table 1 outlines a conceptual model for the efficacy of diagnostic imaging presented by Fryback and Thornbury [3].

Table 1 A Hierarchical Model of Efficacy

Level	Efficacy	Example
1	Technical	Resolution, grayscale range and linearity, noise
2	Diagnostic Accuracy	Sensitivity and specificity, ROC parameter
3	Diagnostic Thinking	Difference in pre to posttest probabilities
4	Therapeutic	Change in patient management
5	Patient Outcome	Improvement in condition of patient
6	Societal	Cost-benefit or Cost-effectiveness

The model is intended to be hierarchical. If an imaging modality is not efficacious at the diagnostic accuracy level it will not be efficacious at the levels above. In keeping with this concept, most studies of the effectiveness of diagnostic imaging devices have used sensitivity and specificity as measure of diagnostic accuracy [4]. The area under the receiver operating characteristic (ROC) curve, a measure of accuracy that is free from bias due to decision criteria has been extensively used to evaluate the diagnostic accuracy of PACS image workstations [5-10]. Although measurements of diagnostic accuracy are necessary for evaluating image workstations they are not sufficient for a complete evaluation of a PACS because they overlook communication.

Unlike CT or MRI, a PACS does not produce images of the body but makes images available to physicians where and when they are needed. Availability may have an effect on patient management. Digital PACS has been justified in two ways. First, cost containment is made possible by replacing an antiquated and inefficient film-PACS. Second, images are always available in the right place and at the right time. Neither of these propositions has been tested rigorously but they suggest that a PACS should be evaluated in terms of the cost and efficiency of image information delivery and the effectiveness of patient care.

Ideally, the clinical effectiveness of PACS should be determined by measuring the impact on clinical outcome at level 5 in the hierarchy. Measuring outcome is an admirable (and politically correct) goal but when a digital communication system is substituted for an already existing analog system the incremental change in most major outcomes such as mortality, morbidity, or the quality of life is very small. Since diagnostic accuracy alone is inadequate, the efficacy analysis must proceed at a level where an improvement in the process of delivering image information will improve medical management which, in turn, will improve the clinical outcome. We have attempted to identify process measures that can act as outcome surrogates.

A problem Oriented Model for Image Information Delivery

Image information is the useful data that is contained in images and in the reports about those images. The model does not require that images are physically moved from place to place just information about the images. The model assumes that imaging examinations are obtained for the purpose of solving clinical problems. The request for an imaging exam sets in motion a series of events that are shown in Table 2.

Some of the events belong to the clinical unit and some of them belong to radiology. Events such as viewing the exam by the clinical unit can lead to a management decision without input from radiology and some events such as issuing a report by radiology can go unnoticed in the clinical unit. Information is exchanged between the clinical unit and radiology during either direct or indirect encounters. The model provides a framework for collecting data about the delivery of image information. Of particular interest as a surrogates for clinical outcome[11] is the time between requesting the examination and either making a management decision or taking a clinical action. The time from making the image information available by radiology until it is accessed by the unit physicians is used as a figure-of-merit for the communication efficiency of the PACS.

Table 2. The Problem Oriented Model for Image Information Delivery

Clinical Unit Events	Clinical Unit- Radiology Encounters	Radiology Events
Clinical Problem		
Request Exam		Perform Exam Retrieve Old Exams Interpret Exam Issue Report
View Exam	Display	
Review Report	Telephone Report Consultation	
Management Decision (Clinical Action)		Archive Exam

Efficiency is not the only component of diagnostic value. The efficient delivery of inaccurate information does not constitute good patient care. We are developing a mathematical model for diagnostic value [12] that is based on the notion that an imaging examination is of value to the physician because it aids in diagnostic decision making and medical management. The actual value of an imaging examination depends upon four factors: 1) the nature of the medical problem that triggered the examination; 2) the timely availability of the image information; 3) the probability of each of the four elementary diagnostic outcomes; 4) the clinical impact of each of the four diagnostic outcomes. The model is formalized in the following equation where for each diagnostic category c there is a diagnostic value $dv(c)$

$$dv(c) = \eta [p(TP)g(TP) + p(TN)g(TN) + p(FP)g(FP) + p(FN)g(FN)] (1)$$

and η is the efficiency of information delivery, $p(TP)$ etc. are the joint probabilities of each of the principal diagnostic decision outcomes and $g(TP)$ etc. are the impact of each diagnostic decision outcome on patient management expressed as integer values (-1,0,+1).

The Medical Intensive Care Unit as a Test Site.

Since 1988, the Medical Intensive Care Unit (MICU) of the Hospital of the University of Pennsylvania has served as a clinical unit for developing a digital-PACS with a soft copy workstation and as a site for testing hypotheses about the effect of digital-PACS on image information communication and certain clinical actions [11,13]. The testing is done by making intensive measurements over 4 week periods in either a Film-PACS or a Digital-PACS mode of operation. After operating in one mode for a 4 week period the unit is switched back to the other mode for an equal period of time.

Six types of data are collected: 1) demographic and disease severity data, 2) data about the delivery of image information to the MICU, 3) data about the communication between radiologists and unit physicians, 4) cost data, 5) data relating to the accuracy of image interpretation and 6) data related to patient outcome.

The demographic data such as age, sex, are downloaded from DECRad - the radiology information system (RIS). The main sources of disease severity data are the ApacheIII score [14] and the Charleson score [15]. The data are collected by chart review. Three times a day (6 AM, 11 AM, 3 PM) a questionnaire is printed by DECRad for each of the chest exams. One of the data coordinators uses the questionnaire to structure a data collection interview with the unit physicians that were responsible for obtaining the imaging examination. The interviews are conducted weekdays at 8 AM, 1 PM and 3 PM and once on weekends. These data include the reason for requesting the exam, details about the first encounter with the image and the report, the type of consultation with radiology, the clinical impression about the image findings, and any clinical action decisions that resulted from obtaining the examination. The clock times of the events such as looking at the images are only approximated at the interview. The times are obtained from other external sources. The time that an examination is scheduled is entered into DECRad when the unit secretary calls radiology. The radiological technologist enters into DECRad the time that the chest examination was actually exposed. After the films are processed they are placed on multiviewers by file clerks and a barcode reader is used to indicate their location and the time that they were displayed. These "DECRad times" are accessed and entered into the data base each day. Lapse-time television cameras record the activity around the multiviewers. Each day, a data coordinator reviews the videotape and determines the time that the films were viewed by members of the MICU staff. The workstation stores the name of the person who logs on and other data about the viewing session. These data are stored in a relational database (Sybase©) that can be queried through a spreadsheet (Excel©).

Problem Oriented Diagnostic Categories

The portable chest examinations are divided into those obtained between 5:00 and 7:00 AM for the purpose of surveillance (routine) and those obtained around the clock to solve specific problems as they arise (non-routine). Data are collected on all of the chest images both routine and non-routine that are made on a randomly selected cohort of 5 patients that are admitted to the MICU. Conclusions about the examinations made on the cohort patients can be applied to the population of patients admitted to the MICU. Data are also collected on all non-routine chest images obtained on all patients in the MICU.

Conclusions about this subset of all of the images made in the MICU only apply to the non-routine examinations. The subdivision of the portable chest examinations made in the MICU into problem oriented diagnostic categories is shown in Table 3.

Table 3 Problem Oriented Diagnostic Categories

Diagnostic Category	Task	Proportion in Cohort
Routine	Change in status.	.58
Non-Routine		.42
Tubes and Lines	Check Position	.17
Pulmonary and Pleural	Rule-out/Follow-up	.18
Other	Various	.07

Much of the value that radiologists add to imaging examinations comes from their lack of clinical bias and their ability to approach images with multiple tasks in mind. The former is important when there is disagreement or uncertainty and the latter is important when some unsuspected abnormality is found. It has been argued [16] that the value added by marginal events can be very important and it follows that such events should not be neglected in the evaluation of PACS. While serendipitous findings add value to the examination, they are infrequent and are likely to occur with equal frequency in both experimental conditions.

Experience with Data Collection.

Our original studies [11,13] used questionnaires for collecting data. Because of a low return rate, a policy of paying \$1.00 for each completed questionnaire was instituted. This increased the flow but many of the questionnaires were incomplete or seemed to be inaccurate. A data coordinator was then employed to collect the questionnaires and get complete data. This evolved into the current system of having a data coordinator question the staff. The penalty for this approach is that it is labor intensive. Data cannot be collected on all examinations all of the time and sampling is necessary.

We also have found that people have difficulty estimating the time of day accurately. (Sometimes, they enter times that will make them or their service look good in the statistical reports). For this reason critical events have been timed externally. For example, the time of viewing films on the multiviewers is determined by using lapsed time recording on television cameras and bar coding the panels of the multiviewer.

We also have found that it is important to have a model for structuring the data collection and the data base in advance of conducting the study. This imposes discipline on the data collection process and allows the institution of measures for data quality control.

Conclusion

Some of the principles that are guiding the evaluation of a hospital PACS have been described. They include: 1) prospective evaluation, 2) comparison of "business as usual" and newly imposed operating conditions (i.e. an experiment), 3) collection of data on a statistically valid sample, 4) collection of data by direct observation as opposed to using questionnaires or using secondary sources, 5) structuring the data analysis in terms of a model.

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Industrial Experiences with Critical Care Networks

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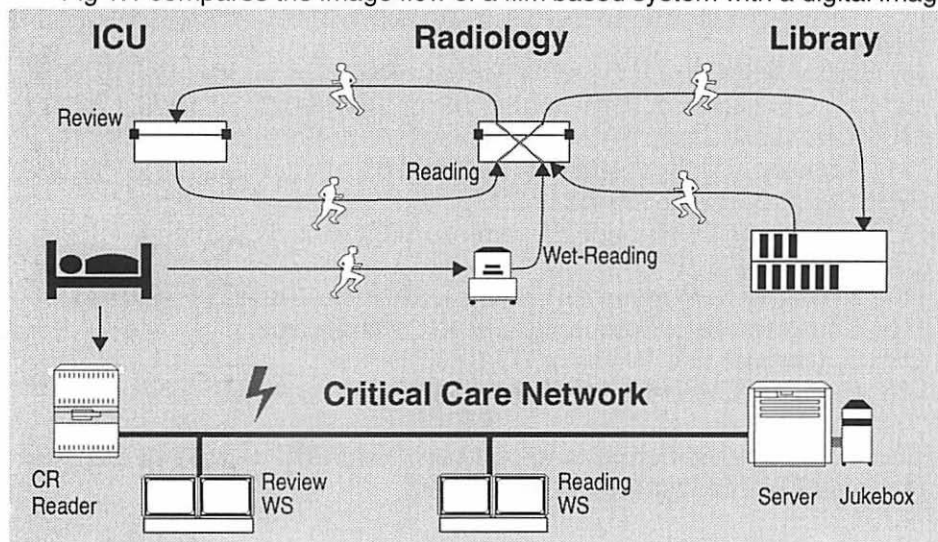
Introduction

Critical care networks are a significant part of the PACS-market. These networks address the known shortcomings of lost films and incorrect exposures. Digital imaging networks, based on computed radiography, softcopy display, and digital archiving, find their greatest benefit in the most sensitive areas of image acquisition and image management: The emergency room and the intensive care units.

We will report our experiences based on various clinical implementations. The main parameters we will focus on are design considerations and cost effectiveness.

1. Image Management and Design Considerations

Fig 1.1 compares the image flow of a film based system with a digital imaging network.



*Fig 1.1: Image flow for critical care image distribution.
Above film based practice, below solution with imaging network.*

ing network. The weaknesses of the film based system are the time consuming film transportation paths from ICU or ER to/from radiology and to/from the short and long term film library. Thus, the images are very often not readily available when needed or simply get lost in one of the departments. Retaking examinations because of improperly selected exposure parameters is quite common. The ER and the ICUs typically contribute 30-50% to the total procedure volume of a hospital, but create 50-70% of the problems in terms of lost or not readily available films.

An efficient way to overcome these shortcomings is to switch to a filmless system, based on Computed Radiography (CR), image viewing workstations in the effected departments, and a digital archive to store the images on a permanent medium like optical disks. Since CR has a vastly wider dynamic range (1:10,000) as compared to film (1:200), the respective retake rate is reduced significantly [1].

Fig 1.2 shows a generic network configuration. Images are brought into the network through a CR-Reader, ideally located in the ICUs or ER, and forwarded to the workstations. On the workstations, images will be kept on the local store as long as the patient resides in the respective ward. Simultaneously, the images are routed automatically to the file server, where they are stored on magnetic disk for fast retrieval. Images are stored on the file server for the length of the patient's stay. Thereafter, the images are permanently stored on optical disks.

It is beneficial to link the imaging network to a radiology information system (RIS). This way, patient information like demographics or reports can be made available to the imaging network electronically.

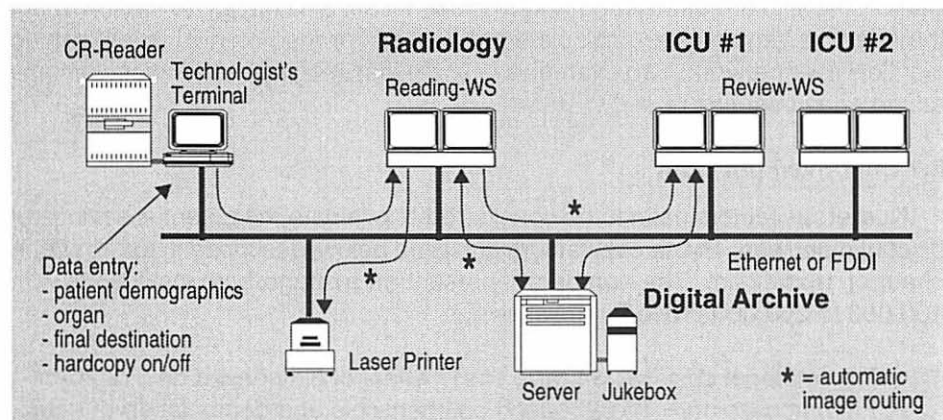


Fig 1.2: Configuration and image management. Image flow indicated by arrows.

For an efficient operation of the imaging network, all the information necessary for image management is entered at the technologist's terminal. Optionally, some of the information can be pulled from the RIS directly or entered through barcoding. As indicated in Fig 1.2, information management at the technologist's terminal involves entry of patient demographics, organ information, steering the

hardcopy output and navigating the images to the radiology workstation as well as to the respective image review workstation on the ward.

Hardcopy printing is recommended at the initial stage of system implementation, until the personnel feel comfortable with the operation of a filmless environment. For printing occasional hardcopies, the laser camera could be replaced by a paper printer later on.

The image viewing workstations need to be equipped with high brightness monitors both for radiology and the wards to provide sufficient contrast for radiographic images.

The need of 2kx2k displays for the radiology workstation is not yet proven. It seems to be sufficient, using more cost effective 1kx1k displays and magnifying details by an electronic "magnifying glass" [3]. For the image review workstations on the wards, 2kx2k displays are not necessary, but brightness and contrast are an issue, especially if clinicians have to interpret images without the benefit of radiology consultation. Organizing studies on the screen should be supported by the system in a predefined way, programmable to the preferences of the individual physician. This method of organizing studies should be user definable, e.g., to present the current study on the left screen and multiple previous studies sequentially on the right screen, or vice versa. Organizing patient studies by ward helps to speed up the reading session.

2. Economical Considerations

The investment of implementing critical care networks has to be justified. As the following paragraphs show, they help to streamline the operation of the organization, and are associated with significant cost savings [2]. In the following, the effective film costs are calculated as a basis for the potential investment in a critical care network. Two examples indicate that imaging networks have many advantages over film based systems.

2.1 Effective Film Cost

Numerous factors have to be considered to evaluate the potential savings of discontinuing film. These cost factors are listed below, described in terms of one sheet of 14x17" film. The numbers represent an average from institutions with 100,000 to 200,000 procedures/year.

1. Film material cost = \$1.84 for a 14x17 sheet of film, based on \$12.20/m²
2. Film processing = \$0.62, based on chemicals and depreciation of equipment
3. Processing salary = \$0.24 (personnel for darkroom, film handling etc.)
4. Film tracking = \$0.34, based on 20% of films not available when needed and therefore to be tracked by technicians and clerks.
5. Archiving space = \$0.50, for short and long-term archiving
6. Archiving salary = \$0.50, for library and film transportation personnel
7. Retake (CR-correctable) = \$8.70 (cost of time and cost of processed film)

8. Lost study = \$60 for the lost reimbursement plus cost of time and cost of processed film, varying with the number of films/study.

Thus, adding items 1-3 above, the cost of a processed film is \$2.70. Including the items 4-6 results in \$4.04, the cost of one film from exposure to the archive.

More over, retakes are necessary because of improperly selected exposure parameters or misplaced film cassettes. Typical retake rates vary usually from 5 to 15%, depending on the ward in which the image has been taken. Lower values apply for ICUs, higher values for the Emergency Room, respectively.

Especially critical to the total film cost are lost studies, since radiology will not receive revenue. Lost study rates vary from 2-10%, lower values apply for the emergency room, higher values for ICUs, respectively. In order to reduce the lost study rate, a number of institutions use two films per exposure (double filming). Thus, both referring physician and radiologist each get a hardcopy. Based on the above parameters, the total cost/film is \$6.97 for double filming (1 image/study), assuming that the lost study rate drops to 0 accompanied by a 5% retake rate at 2 films/retake.

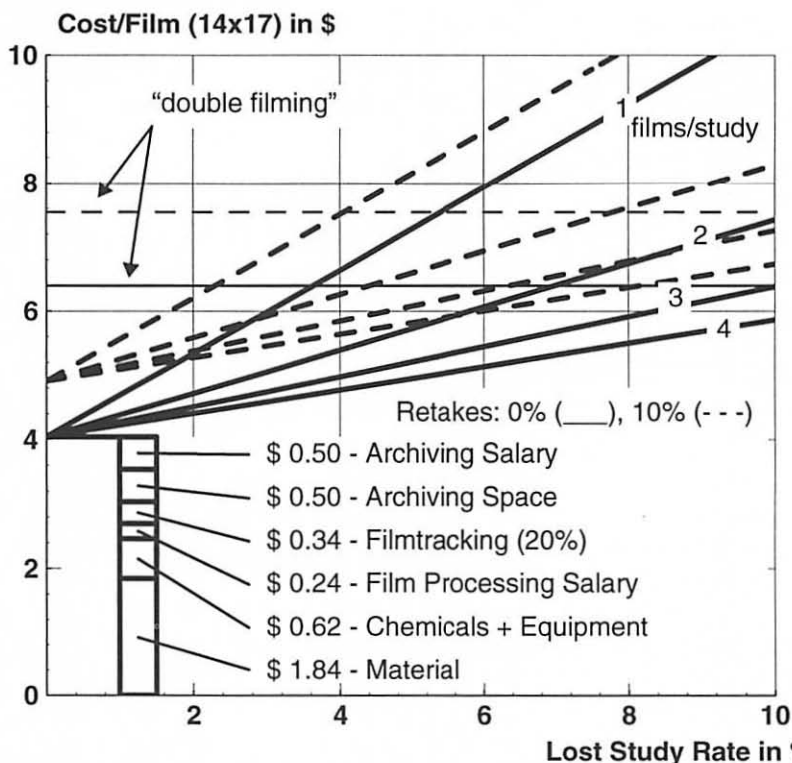


Fig 2.1: Effective film cost varying with retake and lost study rates per one sheet of film. For comparison, cost of "double filming" per image is shown (2 films/exposure, 0% lost studies, 0% film-tracking). Cost per sheet of film drops with multiple image studies, because fixed cost are spread over more films.

Fig 2.1 shows the different components of the effective film cost for different rates of lost studies and retakes, as it relates to one sheet of film.

There are other issues which would increase the potential savings by replacing film with a digital imaging network:

- Time consumption for clinicians will be less, because they save the trip to radiology to view the images.
- Since digital images are readily available for the clinician, the repetition rate will decrease (5% estimated).
- A digital system shows much quicker response times; thus, the patient receives the proper diagnosis in a timely fashion which saves cost of additional expensive treatment.
- Simultaneous display for ER physician and radiologist reduces misdiagnosis and lowers the probability of malpractice lawsuits.

It will be left for further investigation, to quantify these cost savings components.

2.2 Break Even Analysis

The analysis assumes that the investment for the critical care network will be paid fully at the start of the project. Thus, the following formulas apply:

1. Year:

$$V_1 = I + rI - (E - O) , \quad (1)$$

where

V_1 = Value of investment at end of first year,

I = Investment,

r = Interest rate / year,

O = Operating cost / year,

E = Effective film cost / year, identical with savings / year.

2. Year:

$$V_2 = V_1 + rV_1 - (E - O)(1 + i) + sI , \quad (2)$$

where

V_2 = Value of investment at end of second year,

i = Inflation rate / year,

s = Service cost rate / year related to investment; because of warranty, there is no service charge in the first year.

Solving the difference equation (2) for V_n becomes

$$V(n) = \left(I - \frac{E - O}{r - i} + \frac{sI}{r(r + 1)} \right) (1 + r)^n + \frac{E - O}{r - i} (1 + i)^n - \frac{sI}{r} , \quad (3)$$

where $n \geq 1$.

The Break Even is given for $V(n)=0$. Resolving (3) accordingly for I/E becomes

$$\frac{I}{E} = \left(1 - \frac{O}{E}\right) \frac{r}{r-i} \frac{(1+r)^n - (1+i)^n}{[r(r+1) + s] (r+1)^{n-1} - s} \quad (4)$$

Since O/E is usually much less than 1, I/E depends basically on r , i and s .

2.3 Examples

The numerical examples are based on the following parameters:

Interest rate $r=7\%$,

Inflation rate $i=4\%$,

Service cost rate $s=9\%$, applicable after first year,

Operating cost $O=\$0.45$ to replace one single sheet of film,

Break Even = 3.5 years.

The operating cost of the digital system will cover the cost of consumables, mainly optical disks. Assuming a 620MB optical disk is about \$80 and can store 195 CR-images at 8MB each using lossless compression 2.5:1, the cost to replace one single sheet of film is \$0.42.

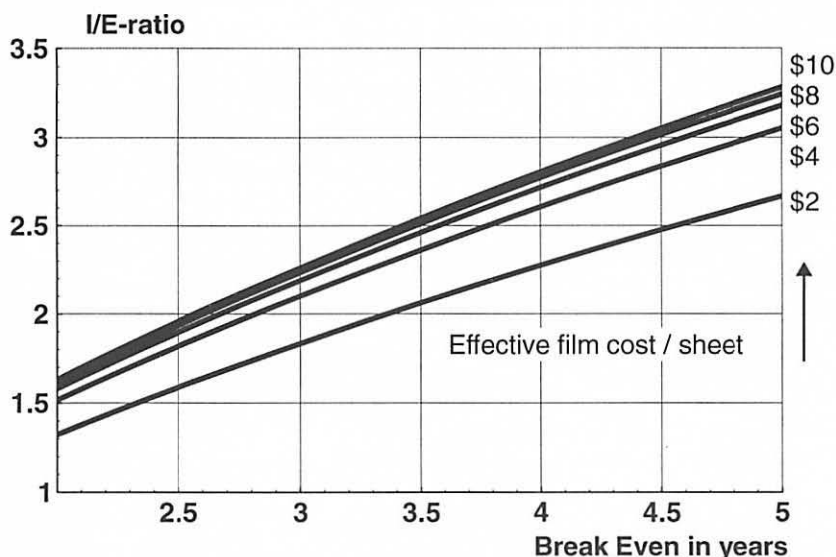


Fig 2.2: I/E -ratio (Investment/Effective Film Cost Ratio) in relation to the number of years to break even. For example, to break even in 4 years, 2.75-times the effective film cost per year could be invested in a digital system (Parameters considered: interest 7%, inflation 4%, service 9%, operating cost \$0.45 to replace one sheet of film by optical disks).

To get an estimate of the investment necessary to achieve a payback within a certain time frame, the I/E -ratio (Investment to Effective Film Cost) in relation to the number of years to break even is shown in Fig 2.2 (4). For example, to

break even within 3.5 years and assuming $E = \$6.5$ from Fig 2.1, the investment $I = 2.5 \cdot E$. Thus, per each film saved, $2.5 \cdot \$6.5 = \16.25 could be invested.

In the following, we will consider two examples. The first illustrates imple-

	ICUs	ER
studies/year	36,500	48,666
films/study	1	3
films/year	36,500	146,000
retake rate	5%	10%
lost study rate	8%	5%
effective film cost/sheet (Fig 2.1)	\$9.66	\$6.25
effective film cost/year	\$352,590	\$912,500
I/E-ratio for 3.5 years (Fig 2.2 or (4))	2.536	2.468
investment	\$894,168	\$2,252,050

Table 1: Investment in critical care networks

menting a critical care network in the ICUs. Assuming 6 ICUs, a total of 66 beds, with 1.5 studies per bed and per day will result in 100 studies/day.

The second example applies for an ER with 3 radiographic imaging rooms, producing 400 images/day, with 3 films/study resulting in 133 studies/day.

Both the ICUs and the ER are operational 365 days/year.

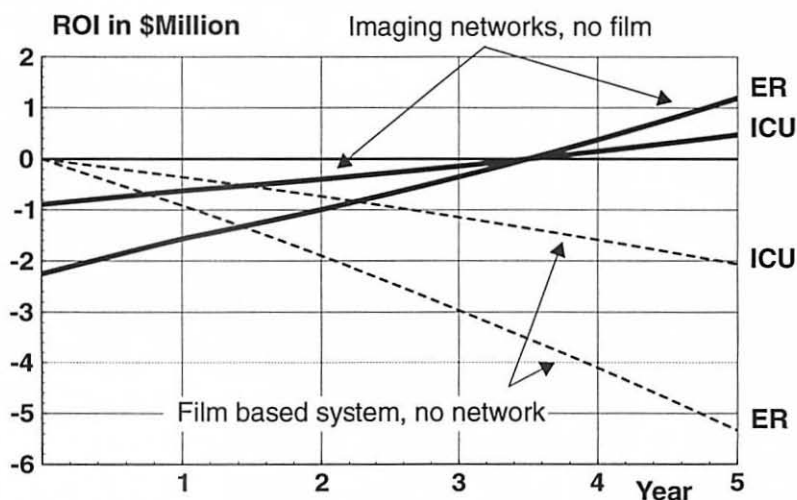


Fig 2.3: Return of investment in either imaging network or film based system.

Ascending curves: Value of investment in critical care networks, film-less operation. Break Even within 3.5 years.

Descending curves: Costs of film based system, if critical care networks would not be implemented.

The appropriate investment for the necessary equipment will be determined to break even within 3.5 years. Table 1 summarizes the results, Fig 2.3 shows the value of the respective investments over time.

Such investments cover multiple CRs, workstations for softcopy reading and image review as well as a file server with optical disk jukeboxes. Significant changes of the interest rate are only of moderate impact. The ascend of the curves within the first year indicates that service charges do not apply for the warranty period.

Most importantly, if the critical care networks would not be implemented, after 3.5 years the accumulated costs of the film based system would amount to more than \$1M for the ICUs and more than \$3M for the ER, respectively. Note that in as little as 1.5 years, the value of the critical care networks already exceeds the cumulated costs of the film based system.

Using the ER-network as an example, the value of the investment after 5 years exceeds \$1Million. Part of this money could be used to update the system to the latest state of technology. Provided that the selected vendor offers a continuous upgrade path, only a fraction of the initial investment has to be paid.

3. Conclusion

Critical care imaging networks based on computed radiography, imaging workstations and digital archiving are the method of choice to address the shortcomings of film based systems in the ER and the ICUs. They help streamline operations and make images reliably and instantly available wherever they are needed. Thus, the quality of health care is improved considerably.

This study shows that the value of the necessary network investment exceeds the cost of the film based system in as little as 1.5 years. The network pays for itself within 3.5 years.

Furthermore, critical care networks provide the seed for totally filmless operation and the infrastructure for expansion to teleradiology applications for remote diagnosis.

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SESSION 20

Teaching Applications

Chair: Bruce J. Hillman

The Digital Academic Radiology Department: Automation and Enrichment of Teaching and Research

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EXPANDED ABSTRACT

Besides the obvious organizational advantages of the digital radiology department in the larger academic institutions, there exists a significant untapped potential of this new paradigm. The digital clinical archive, with the appropriate network and database design, can enhance the teaching and research missions. (Ref 1)

At UCSF, this goal assumes an importance co-equal to that of the purely clinical mission. Two major objective have been identified: (1)The digital department is enabling technology that automates and enhances the use of images for research and publication; (2)It also allows a major redesign of the teaching file concept. A uniform departmental approach, standardized across all sections, is being developed for access to the clinical archive.

This presentation will describe the team efforts of the Laboratory for Radiological Informatics in these arenas. Currently, all CT, MR and CR are being acquired and archived by our PACS. To realize the first objective, the departmental ethernet which supports the desktop Macintoshes of the faculty and fellows has been connected to the PACS via a Departmental Image File Server (Ref 2). A beta version of the server and client (on the desktop Macs) software is currently being tested (Ref 3). This enables access to the image and text information in the PACS.

Since the images coming across to the departmental teaching/research network are converted to PICT2 format (Macintosh standard), all of the commercially available desktop publishing tools can be utilized for image publication and slide making. This potential will be realized at the Macintosh PCs of faculty, fellows and residents.

The ultimate second objective is a "virtual" teaching file in which the actual images of interest remain physically in the clinical archive, but the pertinent clinical, radiological and pathological information, as well as pointers for archive access to the images resides in a separate teaching file database. The realization of the virtual teaching file remains in the future for reasons of network contention and archive aging. These issues will be explored and discussed. However, by moving images from the clinical archive and database over a bridge to a physically distinct teaching file archive and database, essentially the same end result can be achieved. This project is currently in the planning phase.

Selection of the database engine is a key decision. The three major criteria are: (1) efficiency and user-friendliness on networked Macs; (2) ability to cross-platform interrogate and transfer from the PACS database (Sybase on Sun); and (3) ability to handle images as blobs (binary large objects). Commercial developments in the area of object-oriented database systems are being closely monitored. At this time, the two leading contenders for this application are Oracle (excellent cross-platform capability), and 4D (probably the most popular database on the Mac platform). 4D now has an add-on module for SQL queries to Sybase.

One of our concerns is the accumulation of a complete and high quality department-wide teaching file. Therefore, we have established the principle that access comes with a concomitant responsibility: to provide appropriate clinical and pathological information, as well as radiographic findings, for the teaching file archive database. (See Table 1) This is necessary to ensure that the growing teaching file is useful to a broad audience, rather than merely becoming an enlarging collection of random images. Specific methods for implementing this principle are being explored.

Browsing access to this sophisticated image database based upon descriptors of radiographic findings, in addition to the traditional anatomic and pathologic keys, is one of our specific goals, for research as well as education. This provides a richness to the database by enabling, for example, a review of cases of different disease entities that may have similar findings, or a review of the spectrum of findings for a particular disease entity. Automated text scanning of reports of exams selected for the teaching file for radiographic finding descriptors is also being investigated.

Finally, one of the most exciting potentials of this new approach is that the creation of computer aided interactive instructional materials for radiology becomes readily feasible. (Ref 4)

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Table 1.**DESIRABLE ELEMENTS OF A DIGITAL TEACHING FILE DATABASE**

1. The Digital TF DB must include image data, either directly as a blob on the same storage device (magnetic), or by pointer reference to image data on another storage device (magnetic or optical disk).
2. Demographic info should include:
 - Unit or Med Rec number
 - Pt name (optional) - confidentiality issue
 - Study #s (IDXRad Accession #s)
 - Dates of studies
 - Modality/technique i.e. MR w gad, sequence
3. History info
 - Text narrative
 - (This is a required element to move images)**
4. Radiographic Findings
 - Textual descriptive
 - Key word descriptors
 - Third axis of ACR code - future
5. Differential diagnosis
 - Key words
 - Codes
 - Discussion - text
6. Diagnosis info:
 - Diagnosis (text)
 - Diagnosis (code-ACR or modified)
 - Dx proof - path, surgery, presumed
 - Supporting info
 - text of path or opnote
 - ?slides, intra-operative photographs
7. Other
 - Who pulled the case (ID)
 - Must be able to add/combine studies from the same or different modalities, as well as different patients, same diagnosis

The Electronic Textbook of Radiology: Access Methods

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The Department of Radiology at the Medical College of Georgia is preparing an extensive on-line computer driven radiology information system. The information data base is constructed so that it can be used by radiologists, radiology residents, referring physicians, and medical students. The relational data base is built on a logical referencing system which relates text information, radiology images, pathology images and illustrated drawings (anatomic, pathology, technical, etc.). User retrieval of information is provided by keyword entry, closest image match comparison (case-based reasoning) or point-and-click pictorial selection (ACR code). Content of the keyword text entries can best be described as summary lists of diagnostic decision support information. Diagnosis entries are grouped into ten chapters: Brain and Skull including Scalp; Face, Mastoids, Orbit and Neck; Spine, Spinal Canal, Peripheral Nervous System; Skeletal System, Muscles, Soft Tissue & Skin; Heart & Great Vessels Excluding CNS & Neck; Lung, Mediastinum & Pleura; Gastrointestinal System; Genitourinary System & OB-GYN; Vascular & Lymph Systems; and Breast.

These chapters include both pediatric and adult pathology. There are four additional chapters on Physics, Drugs, Nuclear Medicine and Radiobiology. The most direct method of information retrieval is keyword entry. If the user desires information about a particular image, the closest matching series of images or patient cases can be obtained by entry of minimal information about the case or patient image in question. Once a similar patient image or case is brought up, more specific diagnostic information can then be retrieved by selecting a particular diagnosis from a "most probable" diagnosis list provided to the user by the computer. A third alternate retrieval process requires the user to point and click on an illustration of an anatomical site and then to select a pathology from prompting pathology lists which are specific to that anatomical location. A

schematic flow diagram of the methods for information retrieval is portrayed in Figure 1. Currently, text information exceeds eight megabytes with more than twenty thousand keywords and three thousand images.

ELECTRONIC TEXTBOOK OF RADIOLOGY ACCESS DIAGRAM

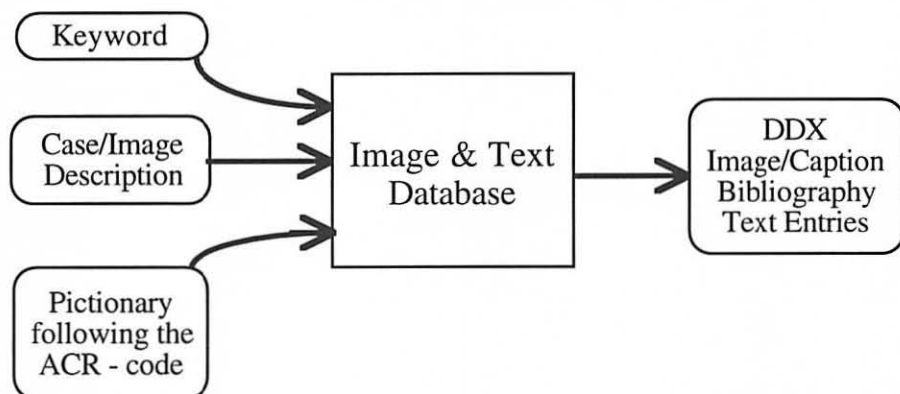


Figure 1. The methods of accessing the text and image entries in the Textbook are illustrated in this access diagram.

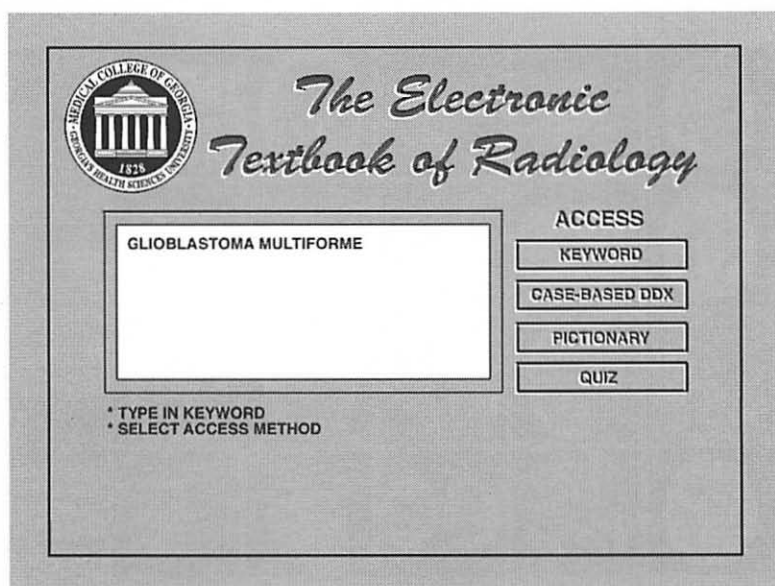


Figure 2. The user can select the method of access or entry to the Textbook through this opening interface.

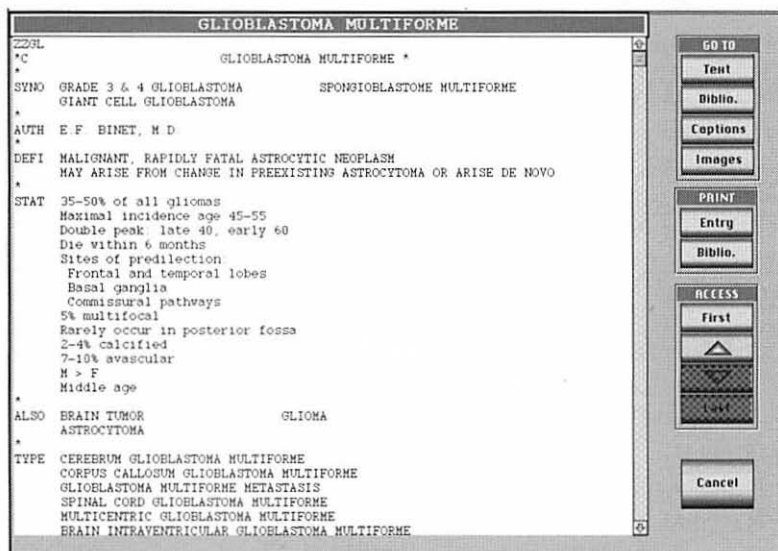


Figure 3. Partial listing of text information available in "Glioblastoma" entry.

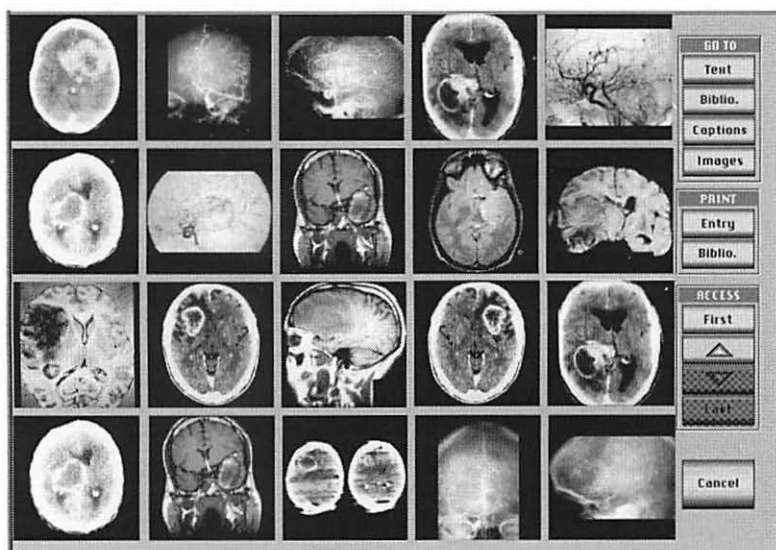


Figure 4. Example of the "thumbnail" image screen which can be used to select an image for full screen display.

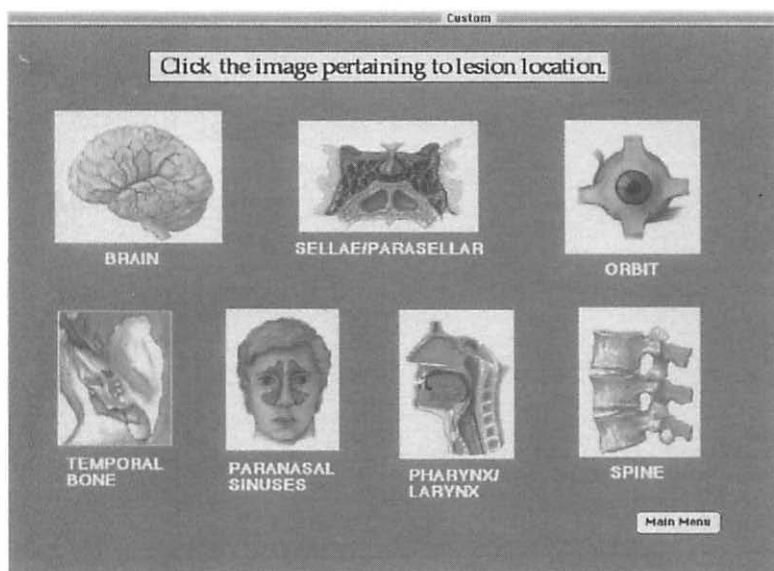


Figure 5. Example of "Pictionary" textbook access method. If the user selects the orbit, Figure 6 is obtained.

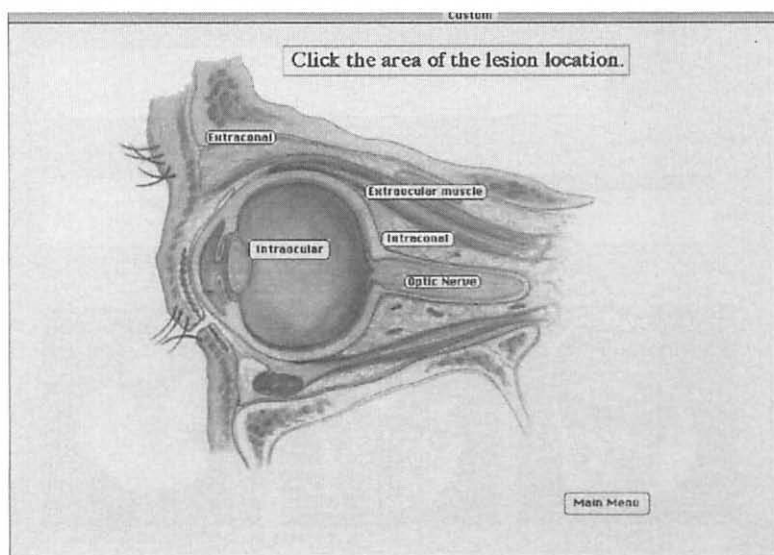


Figure 6. From this screen the user can select the major anatomical sites typically articulated in diagnostic imaging. Site selection will prompt the user with a probable pathology listing similar to the ACR pathology code structure.

Lesion location

Temporal lobe

Skull and contents

Brain and meninges, supratentorial

Temporal lobe

Atlas

Age group

Age 0

☐ Infant

☐ Child

☐ Adolescent

☐ Young adult

☒ Adult

Case history

Congenital / developmental disorder

Congenital / developmental disorder



Procedure

☐ Angiography

☐ CT

☒ MRI

☐ Nuclear medicine

☐ Plain film

☐ Ultrasound

Procedure characteristics

View

Contrast

Vessel

Phase

Lesion characteristics

Homogeneous

Contrast enhancement

Pattern of enhancement

Homogeneous



Associated changes

Edema

Present



Figure 7. Data entry screen for Case Bases DDX. The user may enter search criteria to be used for case retrieval.

Search criteria

Age Adult

Modality MRI

Location Skull and contents:Brain and meninges, supratentorial:Temporal lobe

Case history

General information

Cases retrieved : 2

Astrocytoma fibrillary, grade I-II

Glioblastoma multiforme

Differential diagnosis

Glioblastoma multiforme

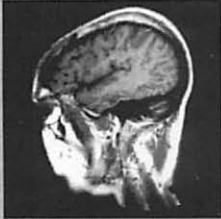
Anaplastic astrocytoma, grade III

Astrocytoma fibrillary, grade I-II

Gangliocytoma

Currently referenced case

Diagnosis Astrocytoma fibrillary, grade I-II



Previous

Next



Figure 8. Case Display Window presenting the list of cases retrieved that match the user search criteria and the differential diagnosis list.

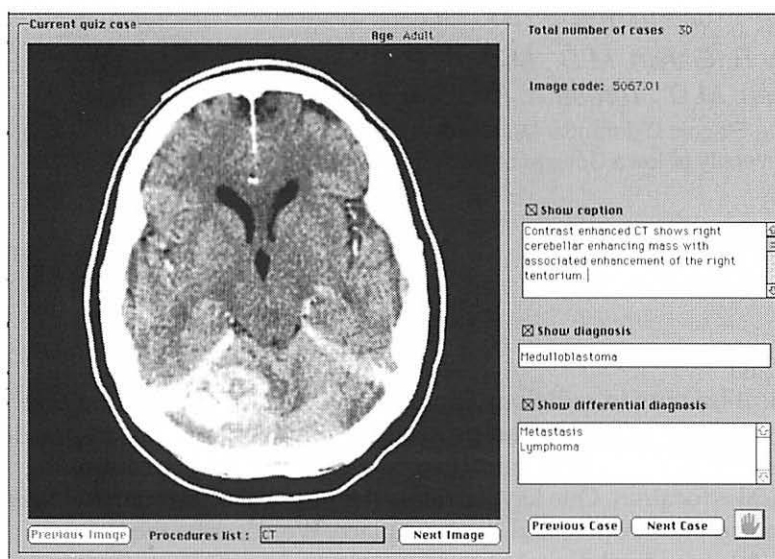


Figure 9. Quiz Window showing the randomly chosen case with the caption, diagnosis, and differential diagnosis displayed upon the user's request.

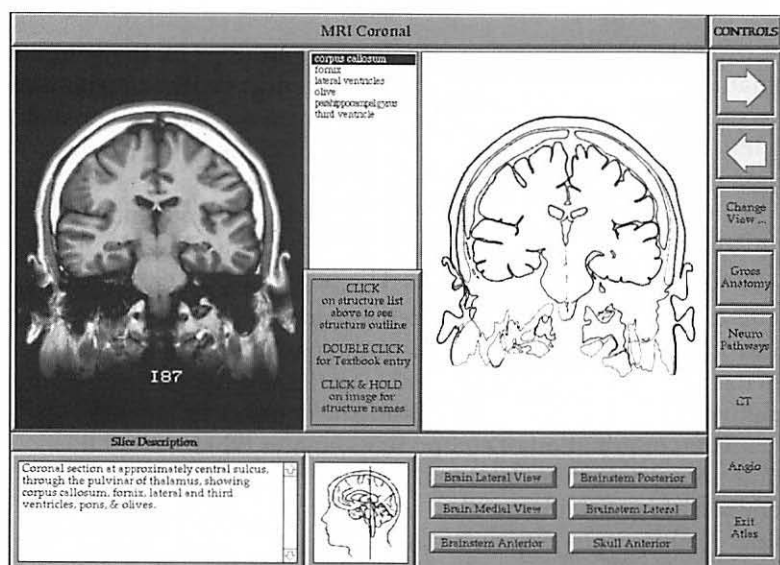


Figure 10. A radiographic anatomy atlas is available to provide more detailed anatomical information.

The Virtual Hospital: A New Paradigm for Electronic Publishing in Radiology

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Abstract

Medical training in radiology should be viewed as a continuum that begins in medical school and proceeds throughout the years in practice. Unfortunately, there are significant barriers to providing continuing medical education. One key barrier is the physical separation between the information source and the workplace. We describe the Virtual Hospital, a medical digital library, created to provide a continuum of information to be distributed to the point of use with tools found in the public domain.

INTRODUCTION

Residency programs in radiology are strained by the volume of information needed to train a radiologist. In addition, the database of information required to remain current has increased and is constantly changing. How then does a radiologist maintain his or her skills throughout a lifetime of practice and integrate new concepts into the "old database?" We think that a solution resides with a combination of multimedia computers, wide area networks, and information developed by academic radiology departments. The potential power of the computer in medicine was recognized as early as 1970.¹ However, a cost-effective link between academic radiology departments and practicing radiologists was not possible until the emergence of wide area networks and inexpensive multimedia computers.

This combination of components creates what we call the "ubiquitous organization" and will, in our opinion, provide the cornerstone of continuing medical education (CME) and distance learning. A ubiquitous organization provides a digital representation of key services usually associated with a physical facility. These services

are continuously available at a distance, thereby extending the reach and power of that organization.

An academic radiology department consists of components that are similar to any large organization. There is a physical facility, the people who work within the department, and current information that is stored in various forms (memory, books, films, teaching files, slides, and electronic databases). At the present time, radiologists must work at the physical facility or travel to a national meeting in order to access this information. Fortunately, most of these data can now be represented digitally with multimedia computers. Text, high-resolution color images, digital movies, and sound allow us to understand complex concepts that have been difficult to convey by word alone. Wide area networks allow us to transmit these concepts beyond the physical boundaries of the department library or teaching file to the workplace where they are required. Thus, we create an organization that extends the use of current information both within the department and outside, allowing new skills to be acquired while remaining in a distant community.

This "just in time learning" allows the practitioner in the field to access information when it is needed rather than attempting to maintain the full database in memory. Delivery of information, at the time of need, to practitioners in their offices or homes is efficient, and we think it represents the future of CME. In order to move toward this new paradigm for learning in radiology, we are creating the Virtual Hospital, which is a continuously updated digital medical library stored on computers and accessed through the Internet.

CONTENT WITHIN THE VIRTUAL HOSPITAL

The Virtual Hospital is being created with support from the Department of Radiology within The University of Iowa College of Medicine; the National Library of Medicine; Apple Computer, Inc.; The University of Iowa Hospitals and Clinics; The University of Iowa Hospitals and Clinics Hospital Information Systems; and the Hardin Health Sciences Library. It will contain multimedia textbooks, multimedia teaching files, current diagnostic and therapeutic algorithms, patient simulations, historical information, patient instructional data, and an extensive collection of on-line CME materials. Information for the Virtual Hospital is being gathered from

lectures, teaching conferences, and grand rounds in our health sciences colleges.

COMPONENTS OF THE VIRTUAL HOSPITAL

- **Internet**

The Internet is the worldwide "information superhighway" of today.² Initially created in 1969, its use was restricted for many years to government and university researchers. Currently, the Internet is undergoing a commercial transformation with data traffic doubling every few months. The key to its success has been an open hardware and software architecture that is based on a robust communications protocol called Transmission Control Protocol/Internet Protocol (TCP/IP).

- **World Wide Web (WWW)**

WWW [European Particle Physics Laboratory (CERN), Geneva, Switzerland] is an Internet hypermedia client/server database software technology that facilitates the organization and acquisition of information stored on the Internet.² A WWW server computer organizes information into a coherent network knowledge structure or "web" and is based on a communications protocol known as the Hypertext Transfer Protocol (HTTP). Text files are stored in the Hypertext Markup Language (HTML) file format. In addition to containing text, HTML files contain links to media that are retrieved from distant computers by clicking on a linked underlined word or picture icon (picon). Each link describes a WWW Uniform Resource Locator (URL), which is a unique Internet address and pointer to the related media.

Media in the WWW may be stored in a variety of formats. Text is stored in the American Standard Code for Information Interchange (ASCII) format, images in the Joint Photographic Experts Group (JPEG) and Graphics Interchange Format (GIF) formats, audio in the .au format, and video in the QuickTime™ and Moving Picture Experts Group (MPEG) formats. WWW is a published and documented standard that is available in the public domain for all major personal computers and workstations.

- **Mosaic**

Mosaic [National Center for Supercomputing Applications (NCSA), Champaign, IL] is an application that serves as a WWW client and a Wide Area Information Server

(WAIS) client. Public domain Mosaic clients have been created for the Macintosh[®], Microsoft Windows, and X-Windows platforms.

- **Networked Multimedia Textbook**

A multimedia textbook (MMTB) is a software program patterning its user interface after a printed textbook but incorporating functions beyond those of printed text. These capabilities include free text search and the ability to play video and audio clips.^{3,4} A networked MMTB (NetMMTB) is a multimedia textbook stored on a server and distributed via a wide area network. The NetMMTB is a modification to the user interface of the WWW and allows the presentation of the inherently nonlinear information within the WWW in a more linear fashion.

- **Wide Area Information Servers**

WAIS is a client/server software technology that indexes text on the Internet. Text files are retrievable via key word or from free text using WAIS's powerful search engine.² A WAIS server is a computer that contains and organizes WAIS indices. Public domain WAIS clients exist for all major PCs and workstations.

IMPLEMENTATION OF THE VIRTUAL HOSPITAL

The Virtual Hospital is accessed with the technologies described above. The NetMMTB is the building block for most of the content within the Virtual Hospital, with each NetMMTB containing a variable number of HTML files. Our WWW server is a Macintosh Apple Workgroup Server 95[®] (Apple Computer Inc., Cupertino, CA) running the UNIX operating system and the Hypertext transfer Protocol Daemon (HTTPD) WWW server software (NCSA). The text within each chapter of a NetMMTB is indexed using WAIS and is therefore retrievable from free text or via key word.

The Virtual Hospital may be accessed from the home or office or within The University of Iowa Department of Radiology via the Internet (see "Appendix: How to Access the Virtual Hospital"). The appropriate Mosaic client allows for cross platform distribution. The user begins by selecting the Virtual Hospital WWW server and then browses its services, selecting one, such as an MMTB on the diagnosis of pulmonary embolus. Once the MMTB is selected, the "Table of Contents"

appears, showing the available chapters. The user then scrolls through the chapter by clicking the scroll bar along the right side of the screen. Links to associated media are indicated by underlined words and picture icons (picons). Clicking on a link displays media related to the text.

Patient simulations are drawn from real cases allowing the user a more in-depth experience with the clinical presentation and workup. Chapters within a NetMMTB may consist of medical information, indices, dictionaries, study sheets, and questions and answers, etc. The user may take multimedia notes by using a word processing program that runs concurrently with Mosaic. Users may copy, paste, and save any portion of a NetMMTB for their own future use and reference. However, they are not allowed to modify an original NetMMTB.

CONCLUSION

Academic radiology departments have traditionally focused their teaching on that period of time we call the residency. However, to be effective radiologists we must be lifelong learners. Training should be viewed as a continuum that starts in medical school and persists throughout the years in practice. Currently, libraries of information are separated from the workplace, which restricts their utility. The Virtual Hospital was designed to lower the barrier to acquiring needed information. As a ubiquitous organization, the Virtual Hospital will allow radiologists in private practice and within university environments to continue their education supported by a familiar database that provides both CME materials and helps with decision-making at the view box.

APPENDIX: HOW TO ACCESS THE VIRTUAL HOSPITAL

1. You must have a TCP/IP connection to the Internet. This is obtained by having a workstation wired directly into the Internet or via a telephone line connection using the Serial Line Internet Protocol (SLIP), AppleTalk Remote Access Protocol (ARAP), or Point to Point Protocol (PPP).
2. You must have a Macintosh, Microsoft Windows, or X-Windows workstation and a Mosaic client for your workstation. Mosaic clients can be obtained on the Internet via ftp from [ftp.ncsa.uiuc.edu](ftp://ftp.ncsa.uiuc.edu) by looking in the directory /Mosaic.

3. Once you launch Mosaic, set its Uniform Resource Locator (URL) to <http://vh.radiology.uiowa.edu/> and you will be connected to the Home Page of the Virtual Hospital.
4. To learn how to display images, video, and audio from the Virtual Hospital, use your Mosaic client to connect to the appropriate NCSA Mosaic Home Page for your workstation. This information should be located in the Mosaic's Navigation menu.

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Multimedia Support for Radiologic Technologists: Design and Utility of a Computer-Assisted Support System

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I. INTRODUCTION

Computer-aided instruction and reference systems that incorporate multiple media formats have recently begun to make inroads in radiology and other medical specialties.¹⁻⁴ The performance increases in desktop computing provide a new and cost-effective interface to medical information in the form of text, images, video, audio and animation. Multimedia application programs allow users to access medical information in a non-linear fashion in one or more media formats. Combined with powerful search tools and interactive feedback and testing, medical multimedia is poised to move into the mainstream of medical education and practice.

Multimedia textbook applications have been created for radiology residency training and tested against the traditional lecture format.² Multimedia applications as reference systems in radiology are not as common. The intent of this research was to exploit the digital computer as a reference source for radiologic technologists in a clinical environment to augment, and in some cases supplant, the need for hard copy reference material or supervisor intervention to answer questions concerning patient positioning and technique for radiographic imaging procedures.

The radiology department at the Medical University of South Carolina, a tertiary care facility, employs a number of radiologic technologists on three shifts. The population of radiation technologists often includes part-time employees, recent graduates and students in training, who, particularly during the evening and night shifts have more difficulty in locating answers to their positioning and technique questions. To solve this problem, a multimedia support system for radiologic technologists has been developed. Through a color, touch screen interface, positioning and technique information is presented using text, graphics, photographs, corresponding radiographs, video and audio. Video clips with audio are used to demonstrate patient alignment for selected views. The design and utility of the support system are the primary focuses of this research.

II. MATERIALS AND METHODS

The multimedia support system was developed using SuperCard™ v1.6 (Silicon Beach Software, San Diego, CA), a hypercard-like development environment providing an object-oriented, event driven scripting language. Objects include buttons, text fields and graphics located on cards inside of windows (objects in themselves). The capability of the scripting language was extended with custom programs called external commands (XCMDs) and external functions (XFCNs) that are accessed by the SuperCard™ application for video playback using QuickTime™ 2.0 (Apple Computer, Cupertino, CA).

SuperCard™ offers a highly intuitive programming environment for developing multimedia applications that include text, color/gray scale images, sound, video, graphics and animation. The color palette for images is limited to 8 bits (256 colors), however multiple color palettes can be used, one for each image in the application. Although the video can be captured and replayed in 24 bit color with QuickTime™ 2.0, the requirements of this application did not demand the use of more than 8 bit color video at 15 frames per second (minimum).

The development hardware consisted of a Macintosh™ M68040 computer (Apple Computer) with 8 megabytes RAM and a 200 Mb hard drive. A 640x480 pixel, 14 inch diagonal, color monitor (Apple Computer) was fitted with a pressure sensitive touch screen overlay and controller (Troll Technology, Valencia, CA) to eliminate the need for a keyboard and a separate point and click input device. The touch screen interface allows the system to be mounted in the wall of the radiographic room without the need for a desktop computing area. Radiographs were digitized on a Lumisys™ DIS 100 (Lumisys, Mountain View, CA) and reformatted to 176x176 pixels by 8 bit planes using NIH Image v1.43 (NIH, Bethesda, MD). Photographs were digitized on a common flat bed scanner, and video was imported through a digitized board (VideoSpigot™ by SuperMac, Sunnyvale, CA). Soundtracks (11 MHz, mono) were digitized with a MacRecorder™ (Faralon, Emeryville, CA), and QuickTime™ movies were generated from video and audio tracks using Adobe Premiere™ (Adobe Systems, Mountain View, CA).

The development environment does not limit the design of the user interface to one particular metaphor. In this application, the interface design was based on a frame metaphor. Each visible window never partially overlaps another window to avoid cropping background windows and is presented on the screen not unlike frames on a wall. The contents of a frame can change and a frame can be completely contained in another frame. Figure 1 shows a sample screen in the application that uses the frame design. The idea is to reduce the cluttered look of a floating windowed environment and to provide fixed and therefore predictable locations for commonly referenced data. Other instructional systems for radiology

have been developed using a textbook metaphor to support novice users familiar with a textbook format that includes chapters, a table of contents and index.²⁻⁴

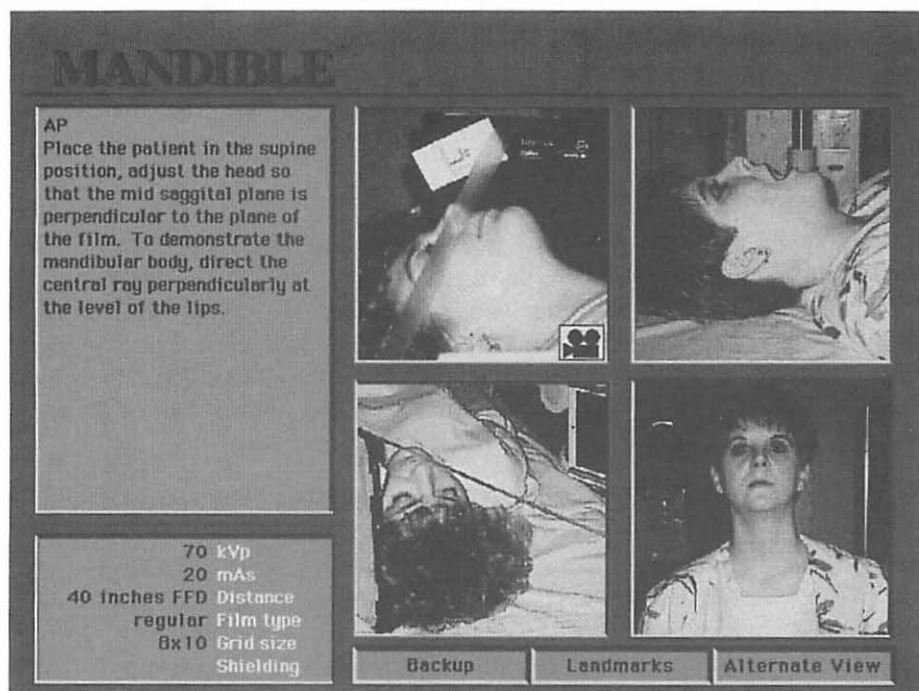


FIGURE 1. A screen showing the frame layout for the mandible series.

The screen in Figure 1 is divided into three primary frames under the screen title bar. The frames are (1) a text field (upper left) used for detailed explanations, (2) another text field (lower left) for technique information, and (3) a large image frame that contains four frame quadrants within the primary frame. Control buttons are located below the image area. The text and technique information for a particular view can be obtained by selecting (touching) one of the available views. The active view is highlighted by a change in frame color. The corresponding radiograph for a particular view can be retrieved by selecting the photograph. The displayed radiograph fills the image area, temporarily replacing the four quadrants. The user can return to the photograph by touching the radiograph. A video icon on a photograph or radiograph indicates that a video segment is available for a particular view and can be accessed by the icon button. At any time, even during a video playback, the user can backup, or select another button or view.

Buttons are provided for navigational control using the control panel interface below the image area. Pull-down and pop-up menus were not used

because they are difficult to access via the touch screen given the pixel size (4.4 mm/pixel) and the menu bar font size (12 point).

Additionally, the screen design criteria included maximizing the screen content with the most relevant information, moving less needed/relevant information to another button access, and minimizing the number of touches necessary to access the most needed information. A multiway tree structure underlies the connections between screens (cards) and information accessible within a screen. The main menu branches directly to one of the radiographic procedures screens. Alternate views for some procedures as well as landmark information are provided as a selection off of a procedures screen, adding one more level to the information structure. Threads for movement in the reverse direction are available for single step backups to previous screens.

In the prototype version under test, four radiographic procedures have been included in the application. The procedures: C-spine, lumbar spine, abdomen and mandible, were chosen on the basis of performance difficulty or lack of performance frequency. The system is currently under test to determine the effectiveness of a multimedia support system for radiologic technologists on (1) the number of retakes due to mispositioning, (2) the retake frequency due to incorrect technique, (3) turn-around time, and (4) the frequency of system access by procedure for the four radiographic series under test. Data is being collected through a survey mechanism and through electronic data collection by the multimedia application and by the scheduling program used by the radiology department.

III. DISCUSSION

A multimedia application was developed to bring positioning and technique information directly into the radiographic room for nearly instant access by radiologic technologists. The low-cost microcomputer application was designed using the multiway tree structure model with a shallow search tree depth and using a screen design of non-partially overlapping windows (frame metaphor).

The system is currently under test to determine the effectiveness of a multimedia support system for radiologic technologists on (1) the number of retakes due to mispositioning, (2) the retake frequency due to incorrect technique, (3) turn-around time, and (4) the frequency of system access by procedure for the four radiographic series under test.

The future of communication formats in medicine will inevitably include multimedia applications. As the screen design metaphors are perfected and perhaps standardized and as users become accustomed to a graphical user interface, the toy-like connotation of these applications will wane. The efficiency of immediate access to larger and larger repositories of knowledge may be the next revolution in medical training and practice, particularly in radiology.

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Multimedia Database for Radiology, Pathology, and Gastroenterology Teaching Files

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I. Introduction:

Traditionally, instruction of gastroenterology diseases includes visual materials of radiology, endoscopy and pathology. A student or faculty who wishes to review case materials must identify which cases to review from a catalog listing, review the patient histories in Medical Records, review the radiology and endoscopy images in Radiology, and review the pathology slides in Pathology. Time is spent in physically moving around to the above sites, and case materials many times cannot be located. Effective teaching of gastroenterology was enhanced by compiling all case materials into a single computerized multimedia database with multiple access sites via an optic fiber local area network with workstations convenient to students and faculty. Users may access other computerized databases interfaced to the net, e.g. laboratory results, medical records, journals on line, as they work through the cases. This database of gastroenterology multimedia case materials is also appropriate to be used for board examination review, for faculty composing lecture materials, and for faculty and consultants locating past cases and/or materials as reference and comparison.

II Background:

Teaching medical students and residents traditionally is by lectures, reading materials and patient exposure during the third and fourth years of medical school, and by "apprenticeship" during internship and residency. The student analyzes cases under supervision of an expert. The expert guides the student in learning to elicit data from the patient, to evaluate data from other sources (e.g., pathology, radiology) and to match assimilated data in terms of diagnostic image patterns¹. Physicians learn to recognize relevant data and images and then search their memory to match them with a diagnosis pattern previously learned. Expertise in medical practice is the result of years of experience in matching patient history, physical examinations, laboratory, pathology and radiology input². A hypothesis for a diagnosis is formed, the hypothesis is tested with all available data. If the patient has features that match a diagnosis, the diagnosis stands³. The practice of medicine is essentially a cognitive problem-solving and image comparison activity^{4,5}. Medical knowledge is expanding, but time for learning remains constant. In view of the educational volume overload and static student learning time, traditional pedagogical methods may no longer be the most appropriate form for imparting medical knowledge. Computing and information technology can be used to

support improved methods of teaching and more effective and efficient use of time in medical education^{6,7}.

There are two major types of computer instructional approaches. One is the intelligent tutoring system (ITS) which is knowledge centered and which leads the user through selected situations. The logic is that the user learns by repeated activities. The other type is computer-assisted instruction (CAI) which is interactive centered with user input determining branching⁸.

A poll of first year medical students who volunteered to work with the computerized sessions indicated that students preferred learning with the method of computerized technology over the method of lectures and slides^{9,10}. Additional applications utilized computerized sessions and videodisk directed toward instruction of first year gross anatomy and general pathology^{11,12}. It was noted that the technology was ideal for individualized instruction to a single student, was an efficient use of student's limited time, was ideal for independent review, and was a way to assure learning experiences¹³.

Recent studies based upon improved computer technology and authoring software find that students who utilized computerized sessions performed significantly better than students who covered the same material in lecture^{14,15}. Senior medical students who used tutorials in pharmacokinetics, the core of clinical pharmacology and therapeutics, scored 35% higher than students who did not¹⁶. Students reported electively spending more time in learning with computers versus learning with text materials because working with computers was a more enjoyable process.

CAI is ideally suited to medical education of gastrointestinal diseases because diagnostic abilities in this area require visual evaluation.

This paper describes development of an optic fiber LAN-distributed database of gastrointestinal disease cases for the purposes of maintaining a single reference for all gastrointestinal case materials, enhancing existing teaching, for supporting retrieval of clinical materials by faculty for use in teaching, seminars, for board examination review, and for a reference for practicing physicians to use in diagnostic comparison.

III. Materials Used:

Hardware: Development and testing of the multimedia teaching file user interface was on IBM PS/2 model M57SLC personal computers with 486SX microprocessors, microchannel architecture, and XGA2 capability. Each had 212 megabytes of hard disk space, 16 megabytes of random access memory, an Actionmedia DVI card for full motion video, an Audio Capture and Playback Adapter (ACPA), as well as a fiberoptic distributed data interface (FDDI) card to allow access to the fiberoptic network. An IBM model 9515 XGA monitor was used for display. Medical image slides were digitized with a Kodak RFS 2035 slide scanner attached to a Future Domain SCSI Host Adapter MCS-700SVP installed in an IBM PS/2 Model 95, 486 computer with 16 megabytes of random access memory and 1 gigabyte of hard disk space. The fiberoptic net configuration consisted of a Novell server (IBM Model 95 MCA), a DB2/2 database host (IBM Model 95 MCA with multiple gigabyte drives), and workstations (IBM 57 SLCs). The net backbone consisted of optic fiber, shielded twisted copper pair wiring, and two IBM 8240 concentrators with copper and fiber panels in each.

Software: Novell 3.11 was the network software. IBM's Network Transport Services (NTS/2) and Netware Client for OS/2 supported the client/server topology for the DB2/2 database. OS/2 2.1 was used as the operating system on the DB2/2 server and the workstations. The relational database for storing information for the medical images and their associated audio and video files was DB2/2 1.0 for OS/2. The user interface and case material interactivity were written in IBM's Builder/2. C/C++ Tools were used for programming dynamic linked libraries (DLLs) and for creating OS/2 presentation manager menus and dialog boxes. Aldus Photostyler 2.0 with Kodak Color Corrector was used to operate the slide scanner.

IV. Methods and Results:

User friendliness and quick access to all images, audio files, video clips, and text files of each medical case were the major requirements in development of the multimedia database and in design of the user interface for accessing the database. Faculty from the departments of radiology, pathology, medicine and biomedical engineering (medical informatics) designed the interface on paper according to their anticipated needs.

Images were scanned at a resolution of 1000 dpi (dots per inch) and 24 bit color in Targa format (TGA) and saved on the database server. TGA images were converted to the IBM AVC digital format (_IM) with a resolution of 640 by 480 pixels and 8 bit color and were also stored on the database server. The basic authoring tool used for developing the user interface (Builder/2) only supported 8 bit color. Using Builder/2, _IM formatted images are displayed much faster than are TGA formatted images. The original TGA, higher resolution images were archived for faculty to use in 35mm slide creations and also for later use when manipulation of higher resolution images of 24 bit color becomes more feasible and economical. Time for scanning varied depending upon whether the scanned image required editing or not. Problems were encountered with the Aldus driver for the Kodak scanner. After saving one image, the software would not allow scanning a second image. Kodak was apprised of the analysis and testing and sent a TWAIN driver which corrected the bug.

DB2/2 and all image, audio, text, and video files were stored on a host on the fiberoptic network. Along with each image, organizational (or archiving and retrieval) information was also stored, e.g., case number, diagnosis, symptoms, organs involved, age and sex of the patient, and type of image (radiology, pathology, or endoscopy). The images and information associated with each case were collected from 35mm slides and from direct inputs from the departments of pathology, radiology and medicine. DB2/2 allowed users from separate workstations to access the information simultaneously.

Personal computers connected to the fiberoptic network were workstations able to access the digitized gastrointestinal case files. Workstations were used by medical students, residents, and physicians. Developing/analyser workstations were located in the radiology department, in the pathology department, and the hospital clinical laboratory conference room which is used for lecture presentations.

An icon associated with the gastrointestinal teaching files allows the user to begin the gastroenterology cases program from the OS/2 desktop. The user is prompted to enter his or her name and password. Distinction of faculty or student was programmed into the user interface via a login name and password requirement to access the database.

Students are allowed to search and view cases. Faculty have additional privileges, such as being able to mark selected cases for later use in presentations and lectures, exporting files, and adding or editing comments to the cases.

After login, the user progresses to an OS/2 presentation manager notebook of a series of pages with listboxes containing the possible search parameters (Fig. 1). Pages are organized by general categories available in the database, e.g., diagnosis, symptoms, and organs involved. Listboxes allow the user to scroll through items. OS/2 presentation manager menus and panels were incorporated into the Builder/2 program by compiling them as dynamically linked libraries with the C Compiler in IBM C/C++ Tools. Listboxes were used because they were deemed to be intuitive to use, i.e. they make it possible for the user to search cases by simply pointing with the mouse and clicking. Also, keyboard entry and related typing errors and misspellings are avoided, making a successful database search more likely. Once the entry of search parameters is completed, all the search parameters selected by the user are passed to the Builder/2 program, which in turn embeds these parameters within SQL (structured query language) statements and initiates a database search.

After having successfully completed a search, cases are displayed on the screen one at a time (Fig. 2). The user may flip through the cases ordered by ascending case numbers. Each case has associated with it two lines of text at the top of the screen; the first line is the diagnosis and case number, and the second line is an abbreviated case history. The viewer may hide or show these parameters for self testing purposes. Immediately below the diagnosis and history all images associated with that case are shown in reduced size. Each image can be viewed in full screen size by clicking on the reduced size image. Images related to audio files or video clips are indicated with a small megaphone or camera icon being imposed on the image. Clicking upon the icon commences playing of the associated file, e.g. barium swallow or oral description of a microscopy slide. The main screen was purposely kept simple and allows only a minimal number of options, such as exit, begin a new search, view comments for this case, export marked file, or display help. Every screen and menu provides help for the user. Help menus were designed with the OS/2 Presentation Manager Information Presentation Facility (IPF) which is the intuitive interface used throughout the OS/2 operating system for displaying help menus.

Currently the database contains a minimal number of cases for development and testing purposes since evolution of the user interface is still in progress. Eventually, the database is expected to hold over 1,000 cases.

V. Discussion:

User comments indicate that the described user interface provides an easy to use point and click environment, which enables the medical student, resident, or physician to search a database for gastroenterology cases of specific interest. The program provides quick and efficient viewing of the multimedia files associated with the selected cases. Digital storage of the files eliminates the past problem of misplaced and/or lost materials. A single, centralized database with easy access is efficient and avoids time consuming process of physically moving between locations of radiology, pathology and medical records. A database of case materials on the fiberoptic network provides fast

and convenient access by faculty and makes the process of duplicating or collecting the files more efficient.

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Figure 1. Fiberoptic network design with Novell server and DB2/2 host.

= fiber
---- = copper

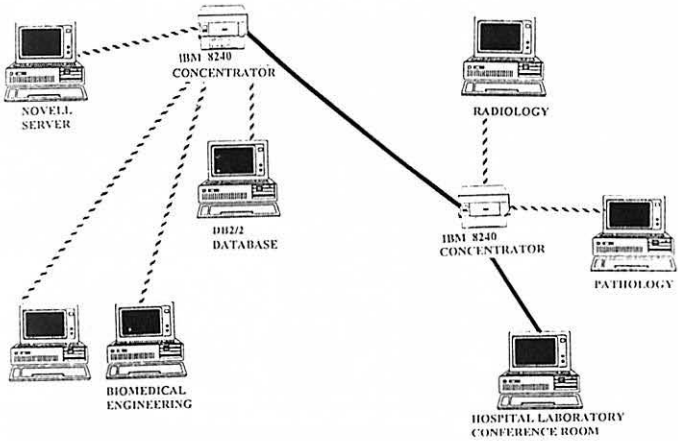


Figure 2. OS/2 Presentation Manager notebook page for entering search parameters.

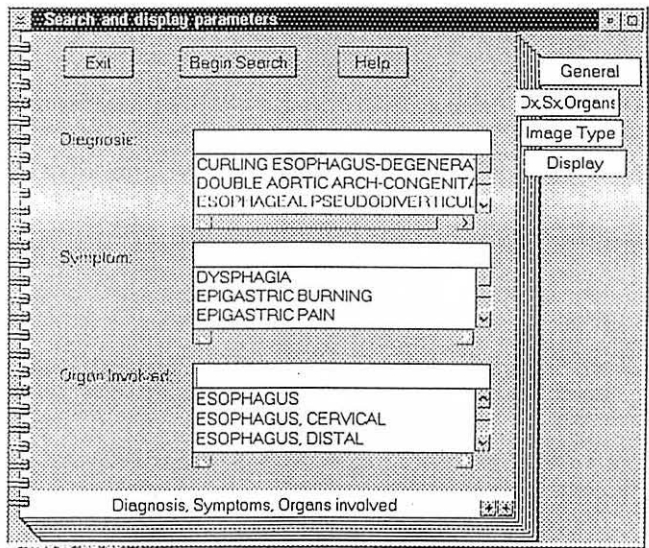
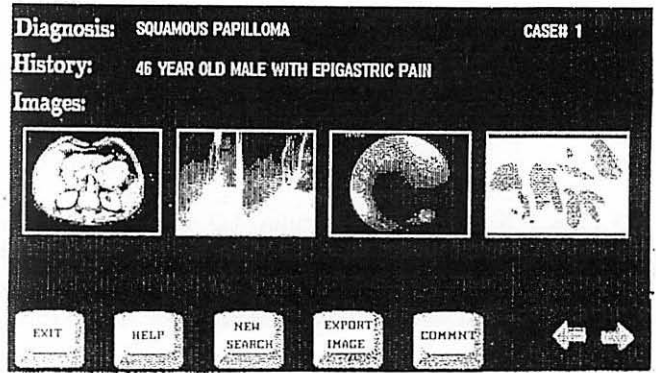


Figure 3. Screen display of a case.



The Visible Human Project—The Role of Radiology

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I. INTRODUCTION

The concept of the Visible Human, as a three dimensional image database derived from serial sections and defining the entire human body, was developed by the National Library of Medicine (NLM) in the late 1980s with the vision that the Library would someday manage digital images in a fashion similar to its management of the biomedical literature today. The digitization of an entire cadaver in computer accessible format was a response to the many concurrent efforts in laboratories throughout the world to computerize isolated small regions of the human body to facilitate human morphological modeling, computer interactive teaching and simulations. At the University of Colorado Health Sciences Center this regional approach resulted in The Video 3D Atlas of Human Anatomy in Cross Section, a videodisk based atlas of photographic and computer generated orthogonal cross sections through the head and neck and articulations of the lower extremity.

Early discussions, at the NLM, of the image management and distribution of the Visible Human included an assumption of high speed networks such that image database retrieval might be as simple and as desktop oriented as an electronic literature search of the NLM's archives today. With the development and implementation of the "Information Superhighway" of the 1990s it appears that access to these large image archives over the network may indeed be feasible in the near future. In 1989 the NLM Planning Panel on Electronic Image Libraries recommended the NLM undertake the Visible Human Project as a first effort in the area of digital image database creation, management and distribution. At that time the Visible Human was described as a collection of digitized photographic images of cryosections, CT and MR images of complete cadavers. It was realized at the time that management of this data might take many forms with regard to classification, indexing and cross referencing. Therefore, as part of the Project the image database would someday be segmented and classified for more functional access. The Project was split into multiple phases for image generation and analysis. In August 1991 a contract was established with the University of Colorado Health Sciences Center for Phase I of the Visible Human Project, to generate the three dimensional database of images defining the Visible Human. The project contract called for the location of the best candidate cadavers, both male and female, between the ages of 21 and 60 years. The desired cadavers would be less than six feet tall, of normal weight for height and demonstrate no signs

of disfiguring surgery, trauma or pathology. More specifically, the design of the project called for the acquisition of three male and three female cadavers. The three cadavers were to be physically inspected and imaged through the whole body with AP radiographs, MR and CT in order to demonstrate their condition. The Visible Human male and female cadavers were then to be chosen from the six candidates by a panel selected by the NLM. The selection panel was composed of radiologists, anatomists and digital imagers. The selection of the Visible Human male, by this panel, was made on September 2, 1993. The cryosectioning of the complete male cadaver was completed in May, 1994. The female cadaver was selected on March 21, 1994 and the cryosectioning will be completed in the summer of 1994. For both the male and female specimens, photographic images are recorded at 1 mm increments as original exposures on 35 mm (Ektar 25) and 70 mm (Ektachrome 100) film.

II. RADIOLOGICAL METHODS

Radiological imaging has been used in this project as a means of validating the quality of the candidate cadavers, defining cadaver landmarks for cryosectioning and as an integral part of the database itself. The Visible Human Project originally required only head and neck MRI but with an increasing clinical interest in MRI of the trunk during 1991 and 1992, the project was expanded to include MR images of the whole body. This large increase in the number of images was partially offset by the introduction of faster imaging sequences. Another major change in the original protocol involved the acquisition of high resolution CT images to be incorporated into the database. According to the original design, CT images were to be obtained at 1 cm intervals to demonstrate the internal anatomy to the selection committee. After selection of the Visible Human (from the three candidates) CT images were to be obtained at 1 mm increments through the entire frozen body. These frozen state CT images were determined from earlier cadavers to be of such low contrast in the soft tissue regions that the protocol was modified to obtain as much data as possible in the fresh state. The amount of fresh data obtained is limited primarily by the condition of the cadaver when it is received at our institution and the availability of the clinical imaging units.

It was anticipated from the beginning that the location of an excellent cadaver would be difficult. Consequently, major efforts from the State Anatomical Boards of Colorado, Texas and Maryland all contributed to the pool of candidate cadavers to choose from. Upon initial acquisition of a possible candidate cadaver for this project a thorough physical inspection and medical record search was undertaken to identify any surgery, trauma, pathology or abnormal morphology. If the specimen passed this preliminary inspection then AP radiographs were obtained over the entire body to reveal pathology or abnormal anatomy, metal implants or fragments and the presence or degree of dental metalwork. With the demonstration of normal radiographic anatomy the cadaver was then imaged with MR. Since the clinical MR signal degrades with both time after death and decreasing temperature it was crucial to obtain the MR images in a timely fashion. MR images of the Visible Human male were all acquired within 24 hours after death. A light embalming solution of 1% formalin was used prior to MRI in order to stabilize the specimen for MR imaging, which is done at room temperature and requires about six hours to complete. No tissue shrinkage of the brain or lungs was noted in test specimens as a result of this light fixation and

MR signal changes from the embalming solution were minimal compared to the degradation in signal with post mortem elapsed time. Plastic tubes, filled with copper sulfate, were attached to the skin of the cadaver from head to foot to provide visible fiducial markers on MRI, CT and cryosection images. The fiducial tubes was designed to aid three dimensional reconstructions and intermodality registrations of the image databases. Transverse and sagittal images were obtained from the head in a standard head coil. The remainder of the body was imaged using a whole body coil and protocols for coronal imaging. A total of 1,038 images were obtained, each in a matrix of 256 x 256 pixels. All MR images were acquired on a 1.5T GE Signa MR imaging unit using both T1 weighted and T2 weighted spin echo protocols. This set of MR images was presented to the selection panel and subsequently incorporated as part of the digital database describing the Visible Human. When MR images failed to reveal any disqualifying conditions, the cadaver was prepared for CT scanning the following night and cooled by storage in a 38 degree cooler. The cadaver was positioned in a wooden box taking care to establish bilateral symmetry for the head, axial symmetry of the body and as close to normal as possible. This usually consisted of an effort to depress the pectoral girdle, dorsiflex the feet as much as possible and extend the fingers to a position as close to the anatomical position as possible. Splints, casts and other positioning devices were not used as they would need to be removed before freezing for cryosectioning and thereby allow positional changes. To hold the cadaver in this position and to keep it in the same position during the cryosectioning, the body was immobilized with Alpha Cradle, a foaming agent commonly used in radiation therapy. A strict anatomical position could not be maintained with the arms because of the size restrictions on the CT scanner. Consequently, the hands were placed over the pelvic area and the arms pulled as tightly to the body as possible. CT images of the fresh, cooled specimen were acquired (within 48 hours post mortem) on a GE HiSpeed scanner at 1mm intervals throughout the head and neck, at 3 mm through the trunk and on 5 mm centers through most of the lower extremity. Subsequent to CT imaging, the cadaver was frozen in the wooden box, in the same position and orientation as during the CT scanning. After the Visible Human - male was selected the cadaver was rescanned in the frozen state at 1 mm intervals throughout the entire body. Size limits of the cryosectioning system required that the cadaver be sectioned into four blocks. Because a 3-4 mm section of tissue is lost from the saw kerf when sectioning the cadaver into four blocks, it was important to define appropriate planes for these cuts that would minimize the loss of anatomical data. Scout views were used to mark the cadaver in the mid-sagittal plane on the anterior surface at three points where the cadaver would later be cut into four blocks for cryosectioning. These marks were defined by the laser positioning light of the CT scanner at locations that would limit all specimen block sizes to be less than 14" x 22.5" x 20.2".

RESULTS AND DISCUSSION

The radiological and cryosection imaging of the male cadaver has been completed. Over 1,750 digital CT (512 x 512 matrices) images of the frozen cadaver and correlated color photographs of planar anatomy have been obtained. An additional 692 axial CT images of the fresh male cadaver provide higher contrast soft tissue. 1,038 MRI images from the same cadaver, but in a different orientation, and a set of 15 AP conventional radiographs complete the Visible Human male database. The CT

scans of the fresh cadaver provide an excellent database for reconstruction and volume rendering of the head and neck area. The 1 mm sections through the frozen cadaver provide for an excellent reconstruction of the skeletal detail for the whole body. The MR images provide additional detail of the soft tissue.

Cryosection photographs and the corresponding CT images are shown in Figure 1. The color anatomical images of the leg and foot were cropped from a high resolution image (2K x 2K pixels x 42 bits) of the entire field of view of the Visible Human male. The field of view for the male specimen was set to the maximum transverse cross sectional dimension for the entire male body. Therefore, these images from the leg and foot are contained in a bounding matrix of approximately 512 x 512 pixels. The color information was first linearly compressed to 24 bits and then combined to an 8 bit greylevel image. The CT image has been windowed for optimum exposure of the soft tissue.

Orthogonal reconstructions (coronal) from the transverse CT images proved to be useful during the cryosectioning to indicate the location and extent of gas filled volumes within the cadaver. These spaces were filled, in some instances, with a blue colored liquid to delineate their extent and simplify the definition of these cavities for image segmentation. Similar processes and data are anticipated for the Visible Human female.

III ACKNOWLEDGMENTS

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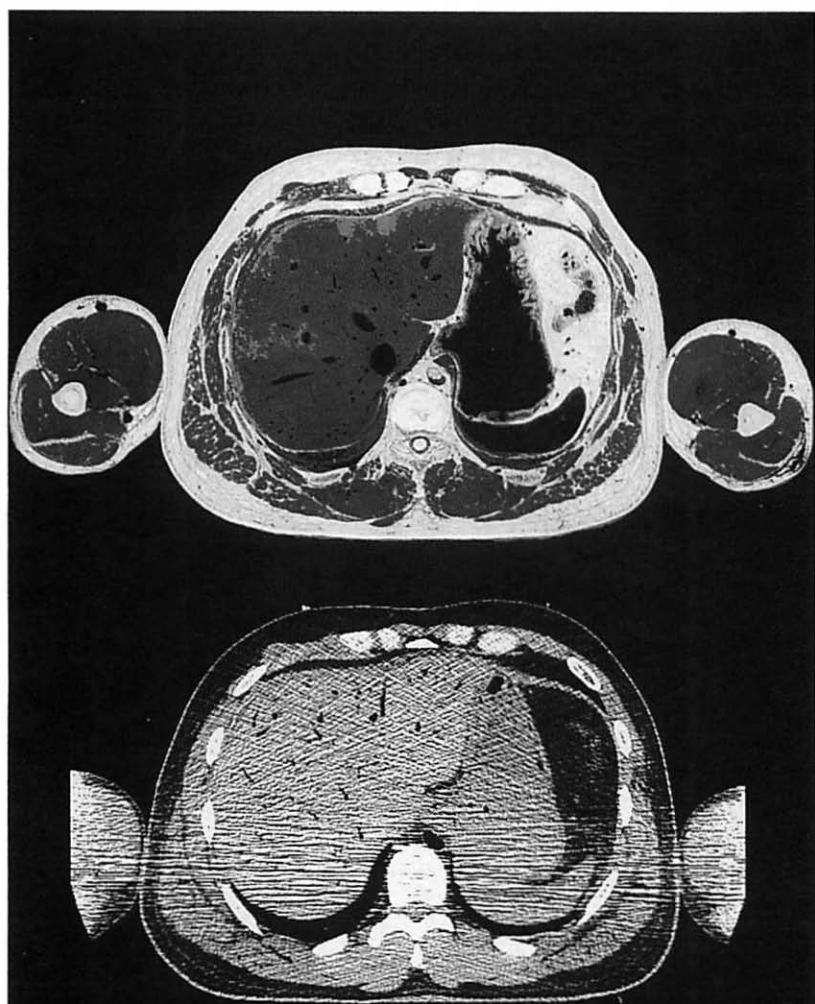


Figure One. Visible Human Male cryosection and fresh CT scan

SESSION 21

Research Applications

Chair: Heinz U. Lemke

Diagnosis of Focal Bone Lesions Using Neural Networks

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Neural networks provide a powerful method of approaching problems that require pattern recognition¹⁻¹¹. Their use is already becoming widespread in medical applications^{1 2 12}. Unlike symbolic artificial intelligence methods developed for rule-based expert systems, neural networks require no explicit preprogrammed rules. Instead, the network is trained using one of several algorithms, such as back propagation, and the network formulates its own implicit, behavior-based rules. Essentially, the network has the ability to "learn" from its mistakes, to generalize based on the data it has received, and to reformulate its own structure within certain limitations dictated by its architecture. As a result, no specific algorithm is developed during the training of a neural network. In this study, we evaluated the ability of a neural network to diagnose focal lesions of bone on plain radiographs.

Methods and Materials

We reviewed the plain radiographs of focal bone lesions catalogued in the teaching file of a tertiary medical center. CT, MRI and other modalities were not used. Cases were excluded from the study when radiographs were technically inadequate to determine lesion detail. Each case was reviewed by two musculoskeletal radiologists in tandem and entered into a computer database for network analysis.

Information was coded according to three basic types of information: demographic, gross anatomic and structural data. In those cases where the patient's age was unknown, the average age for like cases was used. The position of the lesion was categorized according to the bone involved and the location of the lesion within the bone. Twenty-two structural characteristics were analysed and encoded for each case to define the radiographic appearance of the lesion for the network. Data that could not be evaluated on the available images was entered as unknown. Each outcome was translated to a separate binary field and transferred to the neural network.

In this work, we used a feedforward neural network design. Processing units were connected to each other with numeric weights representing connection strengths. The units were organized into a sequence of layers with each unit in

a layer being fully connected to all units in every preceding layer. We used a training algorithm called the "conjugate-gradient method" since it is quadratically convergent and behaves at least as well as backpropagation in tough regions of the error space. In practice, it has proven faster for equivalent problems than ordinary back-propagation¹³.

We used a cross-validation technique to train the network¹⁴. We divided the 709 cases randomly into four groups of approximately equal size. In each run a different group to which the network had never been exposed during the training phase, was used for testing. The results reported for a each case are for the run when it was in the test set. The remaining three groups were used for training the network. This method reduced any bias introduced by overtraining. For each collection of training data, we used singular value decomposition (SVD) to further process the inputs¹⁵. This transformed them into a space in which the input units are aligned orthogonally. We have shown that SVD processing of inputs speeds up training, can identify unused or redundant data, and is required for network convergence in many cases¹⁶. For the task described in this paper, SVD helped on all three counts.

The output layer of the network is organized as a collection of units in which the first unit designates malignancy and the second unit designates non-malignancy. The remaining units are each affiliated with a particular pathologic diagnosis. Ideally, the network would produce a maximum activation in one of the first two units (malignancy and non-malignancy) and in one of the diagnostic units, with all remaining units minimally activated. In practice, the network never achieves this perfect state even for cases used during training since training is usually stopped at approximately 80% correct to maximize its ability to generalize to test cases.

To interpret the output of the network, the cosine of the angle formed by the output vector and each idealized vector is computed using an inner product. We call this number the confidence level. The greater the cosine, the more similar the output of the network is to the idealized vector representing that diagnosis. This provides a complete linear ordering of all diagnoses with respect to each case and is used to provide a differential diagnosis from the network.

We created a diagnostic index (DI) to measure the network's success for each lesion type tested that is calculated as follows:

$$DI = 1 - \left(\frac{IPD}{NPD} \times PID \right)$$

where IPD is the number of incorrect and unique pathologic diagnoses the network selected for a particular pathologic type; NPD is the number of cases coded for that pathologic diagnosis and PID is the fraction of incorrect diagnoses for that pathologic diagnosis. IPD+NPD gives the number of incorrect pathologic diagnoses for a particular type of lesion, adjusted for the

frequency with which the lesion is represented. PID adjusts the equation for the network's ability to correctly diagnose a given pathological type of lesion. While the confidence level is a measure of the strength of the network's choice, the DI measures the actual performance of the network.

Results

709 solitary bone lesions, including 43 separate diagnostic categories, were entered into the database (Table 1). We evaluated several network designs including ones with hidden layers and ones without hidden layers. The network which showed the best performance had no hidden layers and was structured as 95-0-45. This is the network we discuss. The network was first trained to evaluate the likelihood that a lesion was benign or malignant (Table 2). Overall, the network was accurate 85.3% of the time in distinguishing benign from malignant lesions. It correctly identified 163 of 217 (75.1%) lesions as malignant lesions and 442 of 492 (89.1%) as benign.

The network was also trained to give a diagnosis of pathologic lesion type and a differential list of up to nine possible diagnoses. The network correctly identified 397 (56.0%) of the test lesions as its first choice. It included the correct diagnosis 71.8% of the time in a differential list of three lesions. With a differential of five possible choices, the correct diagnosis was included 81.0% of the time. With a nine-lesion differential list the network included the correct diagnosis in the list 87.3% of the time.

We examined the consistency of the differential diagnosis lists generated by the network. With a differential list of 5 possible diagnoses, the network was consistent in selecting exclusively benign or malignant diagnoses in 581 of 709 (81.9%) possible lists. The consistency within differential lists was 89.0% and 66.1% for benign and malignant lesions respectively although not necessarily specific for the correct category of lesion. Hence, although 89.0% of the benign lesion differential lists were consistent within themselves, the correct diagnosis was not necessarily a benign lesion.

The network's diagnostic performance for each pathologic diagnosis with at least three cases is given in Table 1. The diagnostic index for medullary osteosarcoma is 0.96, suggesting excellent performance. This primarily relates to the 72% of the lesions that the network correctly diagnosed. However, it incorrectly placed the remaining 28% of the medullary osteosarcomas (n=22) into 12 different diagnostic categories, nine of which were benign. Similar observations apply to other categories, including enchondroma, Ewing's sarcoma, osteoid osteoma, unicameral bone cyst and giant cell tumor. We reviewed the top three incorrect diagnoses for each lesion type where there were greater than two lesions in the diagnostic category. For each lesion type the incorrect diagnoses are generally ones that may have a similar radiographic appearance to the true diagnosis and might be included on a typical differential list for that lesion. The overall average of the confidence levels the network assigned to the correct diagnosis (0.88) did not differ greatly from the average of the confidence levels it assigned to the first three incorrect diagnoses: 0.90, 0.85 and 0.84.

**TABLE 1 DIAGNOSTIC INDEX AND AVERAGE NETWORK
CONFIDENCE LEVEL BY LESION TYPE**

Diagnosis	Total # of Cases	% Correct Diagnoses	Average Confidence Level (0-1)	Diagnostic Index (0-1)
Chordoma	3	100	087	1.00
Osteosarcoma, Parosteal	6	100	092	1.00
Osteochondroma	50	94	093	1.00
Enchondroma	59	81	094	0.97
Giant Cell Tumor	49	73	088	0.96
Osteosarcoma	78	72	094	0.96
Ewing's Sarcoma	44	68	088	0.95
Chondrosarcoma, Peripheral	9	44	078	0.94
Nonossifying Fibroma	34	58	094	0.93
Unicameral Bone Cyst	40	55	092	0.92
Chondroma, Parosteal	12	67	090	0.92
Osteoid Osteoma	30	67	092	0.91
Hemangioma	16	63	092	0.91
Lipoma	3	67	098	0.89
Chondroblastoma	23	61	087	0.88
Fibrous Dysplasia	41	54	084	0.86
Osteoma	5	60	091	0.84
Brodie's Abscess	21	29	088	0.83
Chondrosarcoma, Medullary	37	36	086	0.79
Eosinophilic Granuloma	26	39	089	0.76
Osteoblastoma	13	31	095	0.73
Aneurysmal Bone Cyst	32	13	089	0.73
Lymphoma	9	11	092	0.70
Chondromyxoid Fibroma	15	27	082	0.61
Osteosarcoma, Periosteal	3	33	070	0.56
Hemangioendothelioma	3	33	088	0.56
Desmoplastic Fibroma	4	25	085	0.44
Ossifying Fibroma	3	0		0.33
Malignant Fibrous Histiocytoma	10	10	081	0.28
Angiosarcoma	5	0		0.20
Brown Tumor	6	0		0.17
Fibrosarcoma	7	0		0.14

TABLE 2
Neural Network Prediction of Lesion Aggressiveness
Versus Pathological Diagnosis

		Neural Network Prediction		
Pathologic Diagnosis		Benign	Malignant	Total
	Benign	442	50	492
	Malignant	54	163	217
	Total	496	213	709

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Digital Bone Structure Analysis

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Abstract: A fundamental question concerning osteoporotic bone is the in vivo evaluation of fracture load (maximum pressure load before fracture). Methods analysing the trabecular structure of bone rather than measuring only its mean mineral density are more successful describing bone structure and strength. It is necessary to develop methods that are sensitive to both, bone structure changes and at the same time correlate with bone strength. In this study the theoretically calculated values of different structure analysis methods are compared to the measured fracture load of human cadaver vertebrae. The bone specimen used were vertebrae of the thoracolumbar spine. A combined thresholding and structure recognition algorithm was used to isolate the relevant data in the CT slices. The segmented structures were then analysed by calculating the fractal dimension, a gradient histogram, a ratio of spongiosa and thresholded trabecular volume, and a gradient variance distribution. Two methods showed a particularly good correlation with fracture load: the ratio of spongiosa and thresholded trabecular area, and the value at 1/2 maximum of the gradient variance distribution.

Introduction: Structure analysis of digital data will be a powerful tool in medicine. As medical imaging goes toward high contrast and high spatial resolution, more data can be used for the analysis of even smaller structures. In the past emphasis in digital image processing focused on noise reduction, edge enhancement, unsharp masking, etc., interpretation and reporting remained unchanged. In the future more attention will be drawn to the development of structure analysis methods which give rise to new useful information for reporting with no additional exposures necessary.

Method: The digital data was taken from CT showing axial views of human cadaver vertebrae. The X-ray intensity in one direction at one detector is given by

$$I = I_0 e^{-\int \mu d\xi} \quad (1)$$

where I_0 is the intensity of the unattenuated beam, μ is the absorption coefficient, and $d\xi$ is a path increment in the corresponding direction of the beam and detector. The measured intensity I is therefore a function of the detector η and projection angle φ . These intensities cannot be used for medical purposes, however, since they do not resemble any living structure, whereas a twodimensional representation of the unknown function μ shows a close correlation to anatomical structures. μ has to be

calculated from the raw data $p(\eta)$ (called projections) given by the logarithmic equation

$$p_{\varphi}(\eta) = \ln \frac{I_0}{I(\varphi, \eta)} = \int \mu d\xi \quad (2)$$

The superpositioning of all such projections leads to a pointprojection function which in the ideal case is a function of distance r from the center only. A real distribution of μ -numbers can be obtained by simply weighing each point projection function $\mu(r)$ with $1/r$, given by the convolution:

$$\bar{\mu}(\underline{r}) = \iint \mu(\underline{r}') \frac{\gamma}{|\underline{r} - \underline{r}'|} d^2 \underline{r}' \quad (3)$$

where γ is a constant of dimension $1/\text{cm}$. Equation 3 can be solved using fourier transformations of this equation using filterfunctions in the frequency domain

$$\mu(\underline{r}) = \frac{1}{\gamma} F_2^{-1} \left\{ H(v) F_2 \{ \bar{\mu} \} \right\}(\underline{r}) \quad (4)$$

Success of any further image analysis depends on the choice of filter function $H(v)$. Since filters are not disclosed to the user, 14 convolution filter types and sizes were compared, by evaluating image quality produced with these filters. The dependence of the structure analysis methods on the type of filter chosen is beeing investigated right now. For reasons of compatibility all slices were calculated with a filter routinely used in the evaluation of quantitative CT having moderate smoothing and edge enhancement characteristics. Apart from the type of reconstruction filter used,

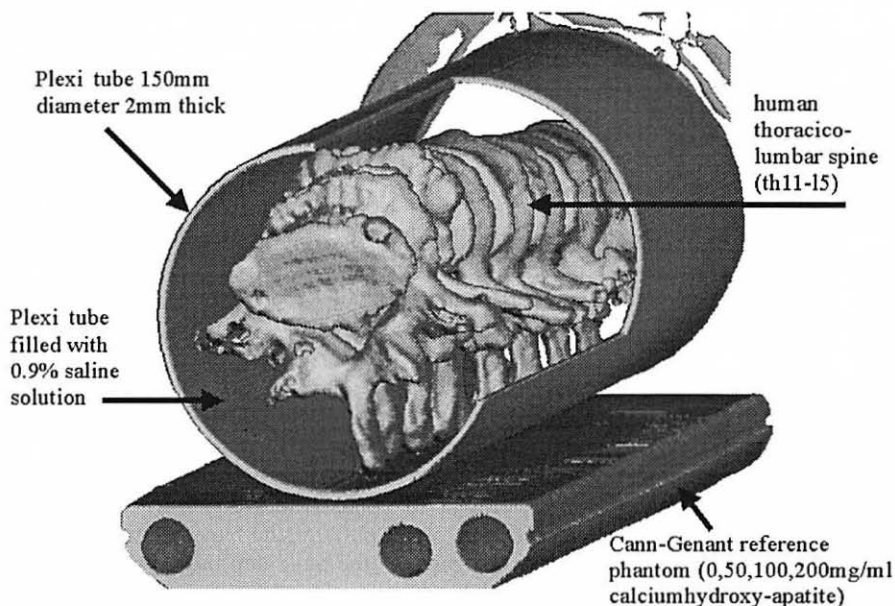


Figure 1: Experimental setup for scanning images used in this study. (3D CT-Reconstruction)

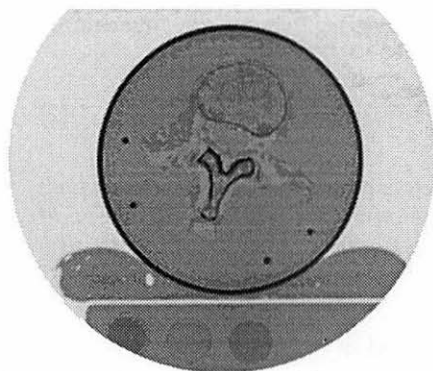


Figure 2: Actual CT-image of the experimental setup. The vertebra is shown close to the bottom plate. The small dots inside the tube are elements for fixing the spinal column

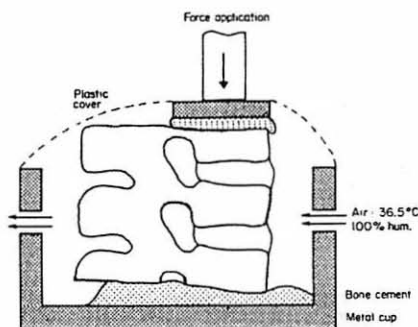


Figure 3: Experimental setup for measuring the calibrated pressure load. Top and bottom Vertebrae are fixed in bone cement.

the spatial resolution depends on the number of projections available for reconstruction. The scantime was therefore chosen 7.6 sec to yield the highest possible number of projections. The upper limit tube current and high tension was chosen for best contrast resolution in this in vitro investigation. The scanner was set to body mode, 120 kV high tension, 175 mA current, and 7.6 sec scantime (Doseindex CTDI was 0.91 mGy/100mAs in center position). The image was a 512x512 pixel square matrix 1.5mm thick (volume elements = voxels). This voxel matrix shows a 200mm field of view, having a maximum theoretical spatial resolution of 391 μ m. The experimental setup is shown in figure 1. One of the original images obtained in this way is shown in figure 2.

Calibrated pressure load: The calibrated pressure load was measured in a biomechanical device. The experimental setup is shown in figure 3. The pressure was applied in cranio-caudal direction with 1 kN/sec and a maximum load of 10kN. The fracture load was reached when the simultaneously recorded pressure - deformation curve markedly deviated from the smooth steady curve, i.e. the relative deformation -load ratio increased.

BMD: The standard bone mineral density (BMD) was measured in quantitative CT (QCT). The correlation of BMD and experimental fracture load served as a standard for comparison of the structure analysis methods investigated. The correlation coefficient of BMD with maximum pressure load (mpl) is $r^2=0.31$ (fig. 9) for the investigated 21 vertebrae of which 15 were male and 6 female aged from 18 to 72 years.

Structure analysis methods: First the trabecular structures must be found and separated from the rest of the image. In this study this is automatically done by a maximum intensity algorithm in the twodimensional plane of the image using the Hounsfield numbers. Contours are found and automatically marked in the image. Everything outside the bone is set to zero. The bone must lie entirely inside the field of view, otherwise "outside" is not defined. In open structures, as in the case of vessels entering the bone in the slice region, small parts of the "inside" are removed up to where trabecular structures close the gaps. In the next step the cortical bone is parts of the "inside" are removed up to where trabecular structures close the gaps. Next the cortical bone is removed from the image. In this step hyperdense metastases are also removed because the segmentation algorithm sees them as belonging to



Figure 4. Automatically segmented spongiosa. The cortical bone including the left and right pedicles is removed. This holds even if osteoplastic or osteoblastic metastases are present in the examined vertebrae, because they will also be removed.

cortical bone. Hypodense metastases are not removed and will have to be considered separately in the analysis methods. The result of a segmented trabecular structure making up a vertebral body is shown in figure 4. All following analysis methods operate on this data set.

1. Fractal dimension

Fractal dimension is taken from chaos theory. It was used to describe complex behavior of complex chaotic motion in so called Poincaré maps. Since the strength of bone is related to the complexity of the supporting trabecular structures, the fractal dimension is in theory related to maximum

pressure load the bone is able to withstand. This method only works if all particles are isolated and their borders marked in the image. In this case the encountered noise made marking these structures a lottery, the outcome depending on where the algorithm started isolating the structures. If no marking was applied the fractal dimension gave only information about the roughness of the surrounding cortical bone.

2. Gradient histogram

The gradient histogram shows the frequency of intensity gradients between neighbouring voxels. The difference in hounsfield units (HU) to the six next neighbours (horizontally, diagonally, and vertically) was projected in 200 intervals 1 HU wide each. The histograms showed a maximum at very small differences and falls off to zero within a few channels. A similar behavior was found in all vertebrae. The idea was to extend the calculation to neighbours further apart and to determine the variance between the different gradient histograms. This method developed into the calculation of a gradient variance distribution described in part 4 of this section.

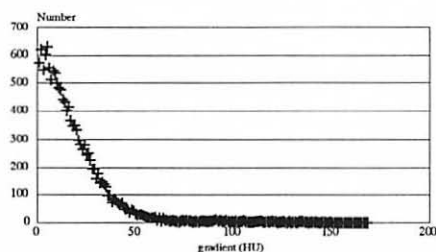


Figure 5: Gradient histogram. Peak value 630 and half width half maximum is 20 HU.

3. Ratio of spongiosa to thresholded trabecular volume

The thresholding technique is attractive due to its simplicity. The Hounsfield units obtained are transformed into calciumhydroxy apatite concentrations by linear regression using the concentrations known from the Cann-Genant phantom

$$\text{conc.} = a \left(k \frac{\mu_{\text{object}} - \mu_{\text{H}_2\text{O}}}{\mu_{\text{H}_2\text{O}}} \right) + b \quad (5)$$

where k is a constant evaluated to normalize the expression in parentheses to -1000 for μ_{air} , and $\mu_{\text{H}_2\text{O}}$ is the absorption coefficient for water, the constants a and b are

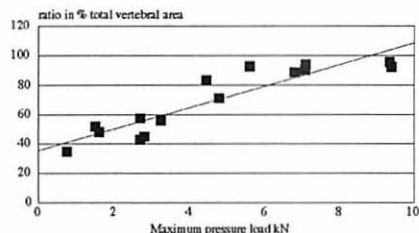


Figure 6: Correlation of trabecular bone content (in % of total area) with maximum calibrated pressure load. Correlation $r^2=0.85$

$$ttar = \frac{\text{voxels in the range 125 - 400mg / ml}}{\text{total number of voxels}} \quad (6)$$

The dimensionless ratio $ttar$ correlates very good with the experimentally determined mpl sustained by the vertebrae (fig. 6). The other advantage of this method is its simplicity, once general thresholding values have been chosen. The values given here (125 to 400 mg/ml) have worked well with this sample of vertebrae. This thresholding range is updated constantly as more vertebrae are scanned, and might be subject to change with a larger or different sample. The algorithm already contains parameters such as area and BMD, they need not be measured and calculated separately.

4. Gradient variance distribution

The gradient variance distribution calculated across the segmented trabecular area, is shown in figure 7. It is related to the size of the particles found in the image just like the fractal dimension, however, it is not necessary to detect and mark every edge. For a given partition of the image into n subdivisions a pyramidal square averaging algorithm determines the average calciumhydroxyapatite concentration for each subdivision. The first step is a subdivision into one square (=no subdivision) resulting in the calculation corresponding to the BMD of the vertebra with a variance of zero. As the number of subdivisions is increased, the squares become smaller and eventually reach the size of one voxel. For every subdivision n , a variance of the average concentrations is determined. The variance values are smoothed with a medianfilter and plotted in a diagram variance vs. n (fig. 7). The distributions start out with a steep rising linear part (n about 5 to 10), then changes

Figure 7: Gradient variance distribution

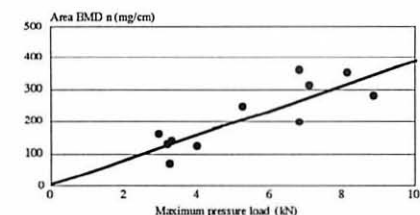


Figure 8: Correlation of gradient variance and density area product with maximum pressure load. Correlation $r^2=0.74$

into a slower but roughly constant rise. The value n for which the curve reaches 1/2 of the BMD calculated in the first step is correlated to maximum pressure load (mpl) for

calculated by linear regression from the four known concentrations found in the image. Then the concentrations calculated by equation 5 are divided with a thresholding interval starting at 125 mg/ml and ending at 400 mg/ml into two groups. The number of image voxels falling into each group are counted and yield the thresholded trabecular area ratio ($ttar$), which in turn is directly related to the relative content of trabecular bone in the vertebral body.

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this vertebra. The (squared) correlation coefficient for the 21 investigated vertebral specimen was $r^2=0.74$ (fig.8) with values of n between 10 and 30. In principle all values in the slower rising region can be used for correlation with maximum pressure load (mpl), a connection with the BMD, however, yields best correlations with mpl. The peak value reached for large n ($n>100$) differs somewhat for different vertebrae, but does by itself not correlate to bone strength. This corresponds to the behaviour of the width at half peak value found in the analysis of the gradient histograms (see part 2 of this section).

Discussion: The BMD is an easy parameter to measure in vivo and gives good agreement with bone strength if the size (or volume) of the vertebrae and the structural patterns are also taken into account. The bone mineral density has been clinically accepted as a helpful parameter for reporting, even though correlation to actual bone strength measured in the biomechanical device is poor (fig. 9). Structure parameters discussed in the previous section (i.e. thresholded trabecular area ratio and

gradient variance distribution) make use of the powerful combination of BMD, area and structural patterns found in the image. However, in vitro results have to be clinically tested. To major aspects have to be investigated before clinical test can be prepared: 1. How do these methods behave, if image quality deteriorates? This will be the case when X-ray dose is reduced to in vivo acceptable levels.

2. How sensitive are the methods to positioning errors? The scan will have to be set close to the bottom endplates of the vertebrae without actually touching them.

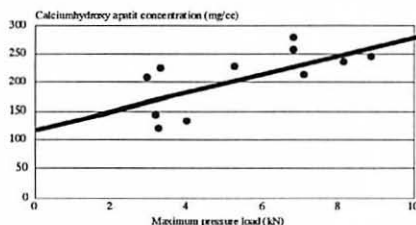


Figure 9: Correlation of BMD with maximum pressure load. Correlation coefficient $r^2=0.31$.

Studies looking into these questions will give answers in the near future.

With the predictive power of the thresholded trabecular area ratio, more precise reports may be given, with no need for additional patient exposures or increased evaluation efforts. The consideration of structural patterns found in the image may give earlier indications of bone composition changes, than BMD measurements alone.

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Image Quality Evaluation Using Phantoms: Detection Versus Discrimination Tasks

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Introduction

The ACR accreditation phantom¹ contains three types of targets: fibrils, nodules, and microcalcifications. The objects within each type are designed with progressively lower contrasts and an evaluation typically consists of counting the total number of objects visualized. For example, at least 4 fibrils, 3 groups of microcalcifications and 3 nodules must be seen in order to pass the standard ACR evaluation. This evaluation method is basically a *detection* task and, if the steps in contrast employed in the phantom design are too coarse, subtle changes in image quality could be undetectable. Alternatively, one might compare the visibility of a given structure to that in a reference image. If the observer is more sensitive to contrast changes in this *discrimination* task than in the detection task, a superior test would result.

The aim of this paper is to investigate whether these two techniques, detection and discrimination tasks, can be used to detect subtle changes in image quality. In order to use a detection task for judging fine changes in image quality, one must use structures with contrast near the visibility threshold. The kVp and mAs can be selected so as to create a 'just visible' structure. All future images should be obtained at the same kVp and mAs setting. This will maximize the chance of seeing any deficits in contrast if these structures fall below the 'just visible' contrast threshold. Of course, this requires that the image be viewed under the same conditions each time, i.e. carefully controlling the ambient light level and screening the light box so that the image is viewed under nearly constant conditions each time. In a *discrimination* task, image quality is measured by comparing high contrast structures in an image to those in a reference image. Again, both images should be taken with the same kVp and mAs. If reasonably large deficits in contrast occur, then these can be identified by comparing the structures in the two images.

Each approach has its advantages and disadvantages. Since the detection task requires that a structure be near the visibility threshold, the combination of a fibril, nodule, and microcalcification may not all be equally as sensitive to reductions in contrast, i.e., if fibril 4 is closest to the visibility threshold, then deficits in quality will most likely be identified by differences in the number of

visible fibers rather than the other structure types. The advantage of this approach is that it is not biased by irrelevant differences between the images, such as minor differences of optical density: two images may have different optical densities but judged to be of the same quality if the selected structures are visible. The discrimination task has the advantage that three comparisons can be made between images: the high contrast fiber, microcalcification group, and nodule, and a quality metric based on the combination of the three judgments since all judgments will be highly sensitive. On the other hand, a discrimination task may be biased by any differences between the images such as a difference in optical density. For example, we have found a slight preference towards brighter images (lower optical density), biasing judgments of contrast.

Methods

Contrast Threshold Experiments

The images for the observer experiments were displayed on an Image Systems MPL21MAX 21" portrait monitor using a DOME board. The DOME board has a 16 bit/pixel memory buffer and 8 bit/pixel display memory. Before each experimental run, the gamma function on the monitor was measured, and the LUT between the buffer memory and display memory set so as to maintain the greatest possible stability in the displayed image between trials. At the background luminance around which the experiments were conducted (40 cd/m^2), the monitor had luminance steps which provided a minimum contrast resolution on the monitor of 1.2%.

Two noise fields were displayed in square 7.5 cm blocks, one above the other on the display, and separated by 1 cm. One field contained the stimulus and noise, the other only noise. The blocks were surround by a background of constant luminance (40 cd/m^2). The trials were not timed and no feedback was provided. The contrast of the signal was varied during the trials and the observer was asked to choose the block which contained the signal. The frequency-of-success data for the two observers were fit to a Weibull function² from which contrast thresholds were estimated. Contrast thresholds were defined as the point at which 92.5% of the trials were successful. Each threshold was estimated using a total of at least 300 trials per observer. The observer was allowed to freely move his head and viewing position and to take as much time as he wished to make a decision on each trial.

The stimulus in the experiments consisted of simulated nodules and microcalcification groups embedded in gaussian distributed white noise. Each structure was created using the formula:

$$L(x,y) = L_{ave}(1 + C)S(x,y) + N(x,y) \quad (1)$$

where L_{ave} is the average luminance of the background, C is the contrast, $S(x,y)$ is the simulated nodule or microcalcification group and $N(x,y)$ is gaussian distributed white noise with a standard deviation of 4 cd/m^2 . This provided a noise contrast level of 0.1 in units of luminance standard deviation/ background luminance. We

used this noise level because this was the approximate noise contrast for an x-ray of the ACR phantom taken between 22 and 35 kVp when displayed on a light box. Nodules were simulated using a mesa function³ which provided a good fit to the luminance profile of the nodules on the phantom images. Contrast threshold experiments were performed with a nodule width of 0.375 cm (size of nodule #3 on an ACR phantom image), and contrast discrimination experiments were performed with a nodule of width 0.7 cm (size of nodule #1 on an ACR phantom image). The calcification groups were simulated with small gaussians in the same configuration as on an ACR phantom image. Both calcification group 1 and calcification group three were simulated with a gaussian of the same size (width = 0.05 cm). Different sizes were not used since this was the smallest size image which could be effectively shown on the monitor.

Experiment 1 was designed to estimate the contrast thresholds for a low contrast nodule and microcalcification group under conditions which mimic those in which the ACR phantom image is scored. Microcalcification group #3 and nodule #3 were simulated because these are the structures which determine whether an image of the ACR phantom will pass or fail according to the ACR criteria.

Experiment 2 was designed to test the contrast discrimination of a high contrast structure in each group. We elected to simulate microcalcification group #1 and nodule #1, because these have the highest contrast (see Figure 1) and the largest size. The nodule trials consisted of discriminating between a nodule with contrast of 0.25 and a nodule of higher contrast. The trials with the microcalcification group used a contrast of 0.8 and higher.

Image measurements

A set of six images of the ACR phantom were acquired with a dedicated mammography machine (Senographe 600T, Kodak Min-R cassettes and Dupont Microvision film). Two images each, at kVp of 22, 28, and 35 were taken. All images were phototimed to achieve near constant optical density. The images were then digitized at 12 bits per pixel for computer analysis using a laser digitizer (Lumysis LUMISCAN 100). The resulting grey levels, ranging from 0 to 3000, are linearly related to the optical density of the film in each 50x50 micron region. (nominally, Optical Density = gray level/1000).

Pixel regions containing calcification group 1, 2, 3 and 4, and nodule 1, 2, 3, and 4 were extracted from each of the images (a higher number refers to a lower contrast structure). The average pixel value was computed over the central 50% of each structure, and over a region surrounding the structure. The pixel values provided an optical density measure which could be transformed to luminance by assuming that the image is displayed on a light box. Thus, grey levels are transformed to luminance values by:

$$L = L_0 10^{(-gl/1000)} \quad (2)$$

where gl is the estimated average grey level and L_0 the luminance of an arbitrary light box. The contrast of each structure can then be computed as

$$C = (L_c - L_b)/L_b \quad (3)$$

where L_c is the luminance in the center of the structure and L_b is the luminance of the background. The contrast estimates for the nodules were obtained by transforming the pixel values to luminance (Equation 2) and then using Equation 3 to estimate luminance contrast. The contrasts for the microcalcification groups were obtained by averaging the contrasts of each of the 6 individual specks in each microcalcification group.

We also estimated the noise level in regions surrounding each of the structures. The noise standard deviation was estimated by averaging the standard deviations of 120 samples of in 10×10 pixel blocks, each separated by 5 pixels.

Results

Observer Experiments

In the first experiment, contrast thresholds were estimated for a simulation of nodule #3 and microcalcification group #3. The contrast thresholds for observer 1 (PG) was 3.1% and 13.47%, for the nodule and microcalcification group, respectively. For observer 2 (MPE), the contrast thresholds were 3.81% and 16.1%, for the nodule and microcalcification group, respectively.

In the second experiment, contrast discrimination thresholds were estimated for simulations of nodule #1 and microcalcification group #1. The contrast discrimination thresholds for observer 1 (PG) was 2.64 % and 6.54 % for the nodule and microcalcification group, and for observer 2 3.0 % and 10.0% for the nodule and microcalcification group, respectively.

Image measurements: Contrast and noise measurements on the phantom images

Figure 1 illustrates the contrast of the nodules and microcalcification groups in each of the six images. The contrast, averaged over the six images, was 7.5% for nodule #3, 5.7% for nodule #4, 32.8% for microcalcification group #3, and 13.5% for microcalcification group #4.

The noise level for each of the six images in units of contrast (luminance standard deviation/ background luminance) was: 22 kVp: 0.047 and 0.054, 28 kVp: 0.058 and 0.057, and 35 kVp: 0.0536 and 0.0618.

Discussion

The average contrast threshold of the two observers for nodule #3 was 3.1%. The measured contrasts of nodule #3 on the six images ranged between 5.4% to 8.6% (see Figure 1), all significantly above observer threshold. The fact that nodule #3 is significantly above threshold over a broad range of imaging conditions is probably why the ACR requires that not only this nodule be seen, but also that a 'circumscribed area in the center of the nodule' be visible.

Consequently, using a detection criteria for nodule #3 as a measure of image quality is basically useless, at least over the range of image quality in this study. It might be more reasonable to use the detection of nodule #4 to judge image quality.

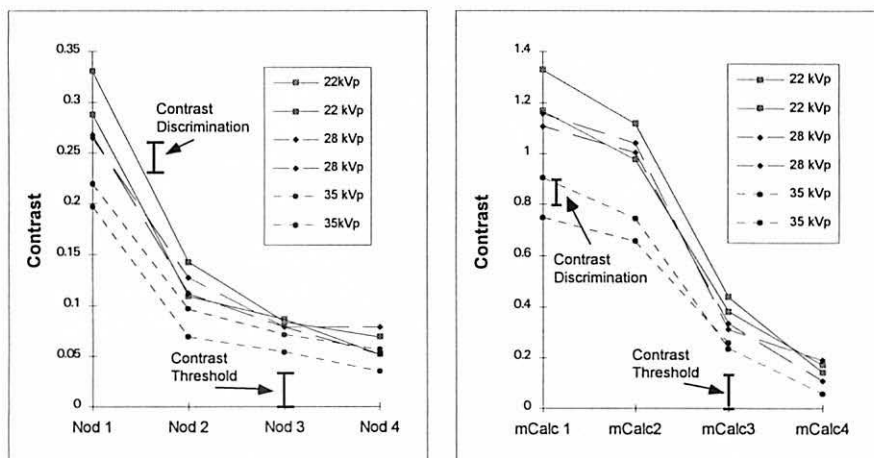


Figure 1. Contrast of nodule 1, 2, 3 and 4 and the contrast of microcalcification group 1, 2, 3, and 4. Also displayed on the image is the average contrast thresholds (nodule 3 and microcalcification 3) and contrast discriminations (nodule 1 and calcification 1) for the observers.

From Figure 1, one might be tempted to infer that even nodule #4 is above threshold because the contrast of this structure was above 3.5% for all of the images. However, the observer experiments were only conducted with a stimulus the size of nodule #3. Nodule #4 is of significantly smaller size, and so the observer contrast threshold for this structure will be slightly larger. These results are in agreement with a parallel study⁴, conducted under completely different conditions, in which 28 images of the ACR phantom were read by eight observers (the six images in this paper were taken from that study). The number of visible nodules, averaged across all eight observers, was above three for the lowest contrast images (kVp = 35), and above 4 for the two best images (kVp = 22).

The average contrast threshold of the two observers for microcalcification group #3 was 14.8%. The contrast of calcification group #3 for the six images in this study ranged between 24% - 38% (see Figure 1). Thus, as is the case for the nodules, this microcalcification group will be visible in all the images. Indeed, in the study cited above⁴, the average number of microcalcification groups seen was between 3 and 4 for this set of the images.

The average contrast discrimination thresholds of nodule #1 for the two observers was 2.82%. This threshold level is plotted in Figure 1, and can be compared to the difference in contrast levels for the six images. Based on this contrast discrimination level, both of the images taken at 22 kVp should be easily discriminable from those taken at 35 kVp, and one of the images taken at 22 kVp (the one with the highest contrast) should be discriminable from both images taken at 28 kVp. And both images taken at 35 kVp can be easily identified as having lower contrast than the other images. A similar prediction holds true for the microcalcifications. The average contrast discrimination thresholds of the

observers for group 1 was 8%. This discrimination threshold provides the ability to differentiate the same set of images as with the nodules.

One implication of the results seems to be that the discrimination task may, in fact, be a much more sensitive test for judging image quality than the detection task. The reason is rather straightforward. The upper and lower contrasts for nodule #1 was 34% and 20% for this set of images. The difference of these contrasts is 4.9 contrast discrimination thresholds, suggesting that some of the images will be quite easily discriminable. On the other hand, the upper and lower contrasts for nodule #3, was 8.6% and 5.4%, a range of only 1.1 contrast thresholds. This means that the contrasts of nodule #3 are much closer together, making it more difficult to discriminate between images in this set.

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Quantitative versus Subjective Evaluation of Phantom Images in Mammography

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Introduction

An x-ray phantom contains structures, called *targets*, intended to mimic clinically relevant features found in x-ray images. They are widely used in quality control of x-ray imaging systems and, in particular, in the American College of Radiology (ACR) accreditation program^{1,2} each mammographic facility submits an image of a standardized phantom as part of the accreditation process. The ACR mammographic accreditation phantom (RMI-156, RMI = Radiation Measurements Inc.) contains three classes of targets called *fibrils*, *microcalcifications* and *nodules*, after features bearing the same names seen in clinical mammograms. Within each class there are several targets of progressively smaller visibilities. In the ACR phantom evaluation the number of targets seen in each class is reported by 3 readers. In order for the institution to pass the phantom image quality evaluation each reader must visualize 4 fibrils, 3 microcalcifications, and 3 nodules.

In this study we sought to determine how sensitive readers are to subtle changes in phantom image quality, and if improvements are possible using quantitative analysis of the images. Since the ACR phantom evaluation is *subjective*, the readers may have difficulty maintaining a precise criteria for declaring a target visible. The between-reader variability may also present problems (one reader may see 4.0 microcalcifications where another will see 3.5). The computerized evaluation investigated in this study is promising as it is objective and does not suffer from criterion drift and between-reader variability^{3,4}.

In the following sections we describe the phantom, the images and the digitization. Several quantitative image quality measures are described. These were applied to the nodule and microcalcification targets on 29 images of the ACR phantom encompassing a wide range of image quality. Also presented are results of subjective scoring of these images by 8 observers who read the images in a standardized manner. A method of predicting the observer scores from the computer measures is described. We conclude with a comparison of the errors in the two types of measurements.

Methods

Phantom: The phantom used in this study was the ACR Mammography Accreditation Phantom. This phantom consists of a removable wax insert in a Lucite holder which provides additional scattering material to more closely match the attenuation of the breast. Imbedded in the wax insert are the target structures consisting of 6 fibrils (F1, F2, F3, F4, F5, F6), 5 groups of microcalcifications (M1, M2, M3, M4, M5), each group containing 6 specks (we distinguish between a *microcalcification group* and the 6 *specks* comprising that group), and 5 nodular nodules (N1, N2, N3, N4, N5). In our labeling convention M1 is the most visible microcalcification group and M5 is the least visible one, with a similar convention for the other target structures.

Images: Twenty nine (29) images of the phantom, referred to as *test images*, were acquired phototimed with a dedicated mammography machine. In order to obtain a wide range of image quality the kVp, scatter blocks, and grid/no-grid conditions were all varied. An additional image used in the analysis was that of the wax insert, referred to as the *insert image*, produced with a non-screen exposure under high contrast conditions.

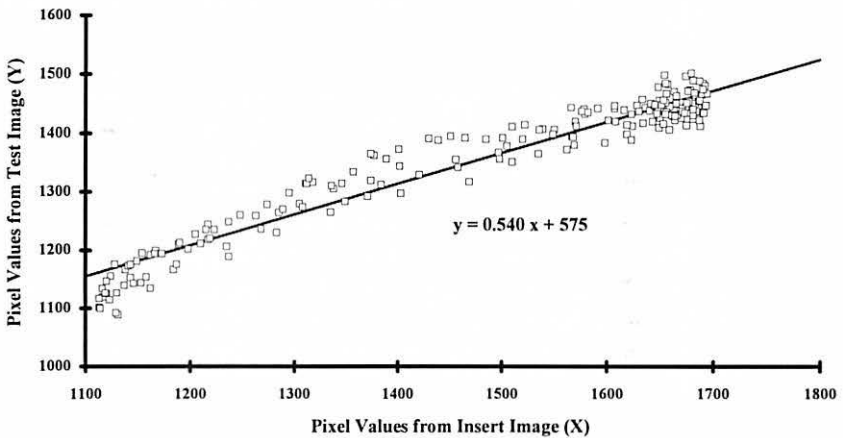
Digitization: All images were digitized at 50 micron spot size, 50 micron pixel size and 12 bits per pixel with a laser digitizer (Lumisys LUMISCAN 100). Care was taken to ensure that the images were oriented in the same manner when digitized so that minimal rotations (typically less than 2 degrees) were subsequently necessary to align them. All digitizations were archived on optical disks using a 1GB per platter optical drive system. Images were analyzed using a high resolution display station consisting of 2 DOME Imaging Systems MD Series boards, each with 20 MB image memories and 1200 x 1600 x 8 bit display memories, 2 Image Systems 24" portrait monitors and an Intel 486-50MHz based personal computer.

Computer Measures: The computer measures investigated fell into two classes: *nodule measures* and *microcalcification measures*. The nodule measures were pixel value, contrast and noise. The pixel value was defined as the average pixel value of the nodule surround. The nodule contrast was defined as the difference between the average pixel value of the nodule and the surround. The nodule noise was defined as the standard deviation of the surround pixel values.

Due to the small size of the specks (even the largest M1 specks only occupied about a 4x4 pixel region at 50 micron resolution), the nodule measures could not be reliably applied to the specks. The approach we took was to develop correlation coefficient based measures (briefly correlation measures) for these smaller structures. We extracted a small region surrounding a speck from the insert image and used this as a template to guide a search algorithm to locate the corresponding speck in the test image. The degree of matching was measured by the correlation

coefficient between corresponding pixels from test and insert images. The alignment procedure consisted of testing the correlation coefficient for a maximum after applying geometrical transformations to bring the test image into registration with the insert image.

Once registration was achieved, various image quality measures were calculated from the pixel values of the insert and test images. The maximum correlation coefficient was one such measure. It describes the matching between the speck density distribution on the test image and that on the insert image ($r = 1$ if the matching is perfect). In addition we calculated the following measures: *speck contrast* and *speck noise*. The pixel values in the test and insert images were fitted to a straight line. The speck contrast was defined as the slope of this line. The noise of the pixel values about this straight line was defined as the speck noise. These measures are illustrated in the Figure below which shows a plot of the pixel values from the 22 kVp image versus from the insert image for the central speck of M1. The slope of the straight line is the contrast measure (0.54 in this case).



Observer Experiments: Each observer read the 33 test images, consisting of 29 distinct x-ray images of the ACR phantom and 4 repeats, in a standardized manner which closely followed that used by the ACR readers. The net score was obtained by adding the individual scores. For example, if 4 fibrils, 3.5 microcalcifications and 3.5 nodules were seen, the net score was 11.0.

Predicting Observer Ratings from the Quantitative Measurements: We needed a predictive model so that we could relate computer measures to subjective measures. This relationship would allow us to convert errors in the computer measures into equivalent errors in the subjective measures. The simplest model that we can conceive is a linear model, and so we used linear regression analysis⁵ with the computer measures serving as the independent variables and the observer score as the dependent variable. Specifically, this analysis models the observer

measure for the i th image, Y_i , in terms of the computer measures X_{ij} (j th computer measure for the i th image) by

$$Y_i = \sum b_j X_{ij} \quad .$$

Error Analysis: The method used was adapted from that developed by Swets and Pickett in the context of signal detection theory⁶. This analysis of variance method separates the observer variance into three independent components. The first component, *case sampling* variance, corresponds to random fluctuations of image quality between images obtained at identical x-ray techniques. The second component, *between reader* variance, measures the inherent variability of different readers reading the same image. The final component, *within reader* variance, measures the variability in the response of the same reader reading the same image, i.e., it quantifies the reader's inconsistency. Denoting these by the subscripts cs , br and wr respectively, we have for the net variance of a single observer

$$\sigma^2(1) = \sigma_{cs}^2 + \sigma_{br}^2 + \sigma_{wr}^2 \quad ,$$

where "1" emphasizes that the variance estimate applies to 1 observer. If the responses are averaged over several observers (the ACR employs 3) the variance of the average observer rating is smaller as the between reader and within reader variations are averaged out. For N observers the expression for the variance is

$$\sigma^2(N) = \sigma_{cs}^2 + \frac{\sigma_{br}^2 + \sigma_{wr}^2}{N} \quad .$$

The error analysis consisted of obtaining estimates for each one of the variance components entering Eq. 2. The 29 distinct images shown included some obtained at identical x-ray techniques (case samples). From these readings we obtained an estimate of the case sampling plus the within reader variance, $\sigma_{cs}^2 + \sigma_{wr}^2$. Similarly, from re-readings by a reader of the same image on multiple occasions we obtained the within reader variance σ_{wr}^2 . Finally, from the readings by the different observers of the same image we obtained the $br+wr$ variance, $\sigma_{br}^2 + \sigma_{wr}^2$. These estimates were used to solve for the three variance components of the observer.

The variance of the computer estimates were obtained in an analogous manner. The different case samples were digitized and analyzed to yield the $cs+wr$ component of the variance. The case sampling component is due to the Poisson statistical variation of the images, and processing and x-ray technique variations. The within reader component is due to positioning variations of the image relative to the digital matrix and interpolation errors. By definition, the computer has no between reader component of variability. Therefore, for the computer measure we have

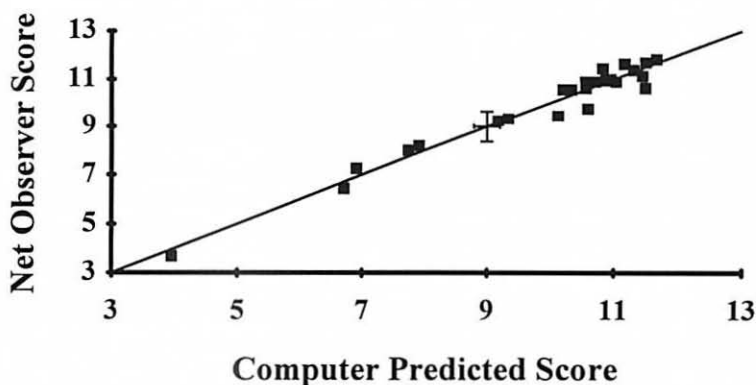
$$\sigma^2(X_{ij}) = \sigma_{cs}^2(X_{ij}) + \sigma_{wr}^2(X_{ij}) \quad .$$

The variance estimates of the computer measures can be used to calculate the error in the predicted observer response using

$$\sigma^2(Y_i) = \sum b_j^2 \sigma^2(X_{ij})$$

Results

It was found that the subjective measures could be well predicted (correlation = 0.98) by the quantitative measures (see Figure below). For this predictive model a combination of N3-contrast, M1-correlation and M1-noise measures were used. We also found that the quantitative measures were less variable than the subjective measures (the variance is smaller by about a factor of 10). Results of the error analysis are $\sigma_{cs}^2 = 0.106$, $\sigma_{wr}^2 = 0.166$, $\sigma_{br}^2 = 0.738$. These yielded for the net variance estimate for a single reader $\sigma_{cs+br+wr}^2(1) = 1.01$. The corresponding computer measure variance estimate was 0.043. The net variance estimate for the average of three reader $\sigma_{cs+br+wr}^2(3) = 0.408$, which is about a factor of 10 larger than the computer measure. The standard errors (i.e., square root of the variance) are shown in the Figure below.



Discussion

We found that there is considerable measurement precision to be gained, almost a factor of 10, by performing computerized analysis of mammography ACR images. Using more readers would only partially solve the problem with the subjective readings because of the case sampling variability, which can only be reduced by employing more images.

Note that the nodule measures make no allowance for (1) uncertainty in the precise location of the center of the nodule and (2) structured noise in the phantom. As these measures were applied to relatively large structures the first limitation is insignificant (the locating uncertainty, of the order of a pixel, is much smaller than

the radius of the N1 nodule, about 100 pixels). The second limitation is also less significant for the uniform background ACR phantom (although there is some Heel effect variation) but it does mean that the nodule measures are not applicable to phantoms (such as the RMI 165) which have a structured background. The correlation measures, on the other hand, have a more general applicability. There is a suggestion that improved phantom-clinical predictive ability might be obtained by using an anthropomorphic phantom⁷. The correlation measure is readily adaptable to such phantoms and work is underway, some reported in an accompanying paper in these proceedings, to further develop the measurement methodology described here.

Acknowledgement

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Artificial Neural Network Registration of Simulated 3 Dimensional Images

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ABSTRACT

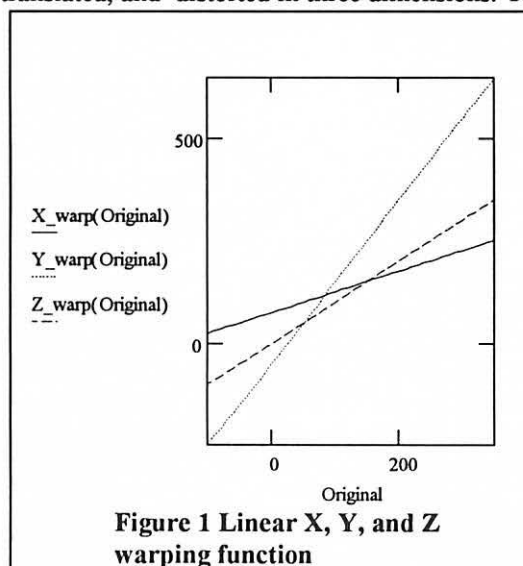
Registration of three-dimensional medical images is important for correlation of images from different modalities and to be able to follow progression or regression of disease. In this paper, we investigate the use of artificial neural networks (ANN) in registering simulated 3 dimensional images. Corresponding fiducial points on the original and translated, rotated and scaled images were used to train backpropagation neural networks with 0 or 1 hidden layer to map between the coordinate spaces. A separate set of points were used to test the neural network mapping between the coordinate spaces. The mean distance error with 5 fiducial points and no error in locating the fiducial point was 0.69 pixels and decreased to 0.07 pixels with 10 fiducials. When a random error of plus or minus 10 pixels was added to the fiducial points the mean distance error was 13.5 pixels for 10 fiducials and 5.70 pixels for 50 fiducials. Back propagation networks with 0 or 1 hidden layers accurately map between coordinate spaces which are rotated, translated, and linearly scaled in 3 dimensions.

INTRODUCTION

Registration of 3-dimensional images is important for comparison of different imaging modalities and to evaluate changes over serial imaging studies. Accurate 3-D registration allows quantitative evaluations over time and correlation of multiple imaging modalities[1,2]. Registration and segmentation techniques can quantitate and determine progression of disease for clinical trials and for clinical assessment of individual patients. Artificial neural networks can perform complex multivariable mappings with accuracy similar to traditional methods and may be less sensitive to noise than other methods[3].

MATERIALS AND METHODS

Simulated three-dimensional images were constructed then rotated, translated, and distorted in three dimensions. The coordinate system was rotated in



the x, y, and z axes. Translations in the x, y, and z axes were also done. Finally, a linear transformation or warping was applied along any or all axes. Figure 1 shows one such warping function above the x and y axes. This type of warping function simulates different scales along any axis. If a linear warping function is assumed, the x, y, and z positions in the transformed coordinate space is a linear function of the x, y, and z coordinates in the original coordinate space. This type of mapping should be well modeled by a 0 hidden layer back

propagation network. The effect of noise in the fiducial coordinate spaces could affect the network structure that would best model the transformation. This type of rigid body transformation is the most commonly-assumed transformation in 3D medical imaging [4].

The original and transformed data was used to train and test the accuracy of a back propagation network, functional link network, and a counter propagation network in mapping between the coordinates spaces. Three to 50 fiducial points from the test images were used to train the networks. The accuracy of the networks was tested on a separate set of points. The effect of noise in selecting the position of the fiducial points was also simulated. The ANN were constructed using Neuralworks (NeuralWare, Pittsburg PA). This neural network development package works on PC and SUN systems as well as several others. The simulated images were constructed using MathCad (MathSoft Buffalo NY). The images were made with several spheres of different size, location and shade.

Back propagation networks with 0 and 1 hidden layers were tested. Linear and sigmoid activation functions were also tested. The inputs were the x, y, and z coordinates of the original fiducial points. The outputs are the x, y and z coordinates of the corresponding points in the transformed coordinate space. The back propagation neural network was trained with sets of 50, 10, 5 and 3 fiducial points with and without random noise of various magnitude added to the fiducials of both

coordinate spaces. Separate test sets of coordinate points were used to test the neural network.

RESULTS

Table 1 Mean error of distance of network coordinate space mapping of test set with rotation, translation, and linear warping

	Network Type				Mean error of distance in training set
	Backprop no hidden layers linear activation function	Backprop 1 hidden layer linear activation function	Backprop no hidden layers sigmoid activation function	Backprop 1 hidden layer sigmoid activation function	
50 fiducials no noise	0.07 sd 0.03	0.05 sd 0.03	0.06 sd 0.03	0.27 sd 0.22	0
10 fiducials no noise	0.07 sd 0.03				0
5 fiducials no noise	0.69 sd 0.39				0
3 fiducials no noise	100.4 sd 34.06				0
50 fiducials + 2 pixels	1.99 sd 0.76			1.79 sd 0.80	1.9 sd 0.6
5 fiducials +- 2 pixels	4.24 sd 2.15			3.05 sd 1.15	1.9 sd 0.6
50 fiducials +- 10 pixels	5.70 sd 2.45	5.10 sd 1.93	3.32 sd 1.67	4.80 sd 2.40	9.8 sd 2.9
10 fiducials +- 10 pixels	13.5 sd 6.11				9.8 sd 2.9
5 fiducials +- 10 pixels	21.5 sd 8.50	21.5 sd 8.57			9.8 sd 2.9

Training set

As can be seen from the above table, back propagation networks with linear or sigmoid activation functions and 0 or 1 hidden layer map between coordinate spaces which are rotated, translated, and linearly warped or scaled with an accuracy of less than 1 pixel. The mapping accuracy is reduced when noise is added to the fiducial points. Larger numbers of fiducial points increase the accuracy of the

network prediction to a level as accurate or more accurate than picking individual fiducial points.

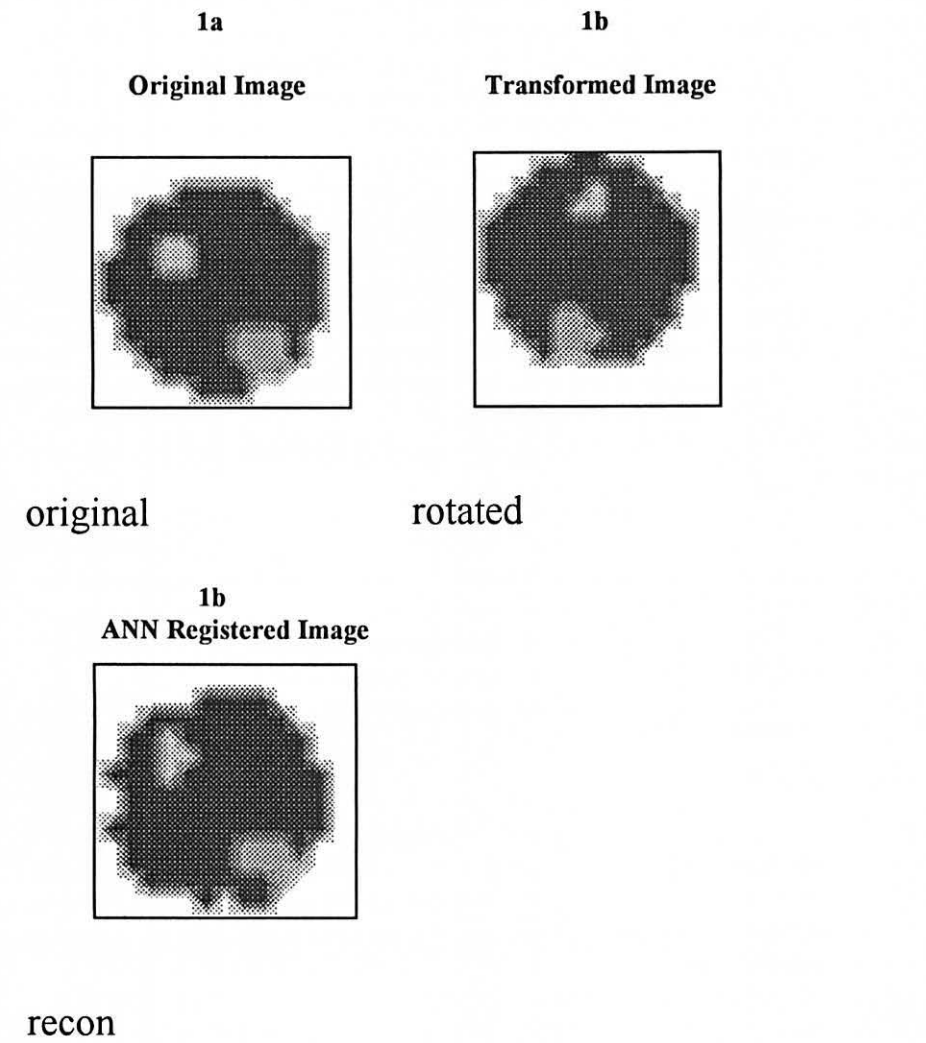


Figure 1 shows original, transformed and reconstructed images. The areas of mismatch are caused by partial volume averaging and interpolation errors. The large pixel size used to construct these images contributed to both of these errors.

CONCLUSION

Artificial neural networks are a method which can be used to map from one three-dimensional space to another three-dimensional space. These simulations demonstrate that with appropriate fiducial points backpropagation networks with no hidden layers and a linear activation can have an accuracy of less than 1 pixel with only a few fiducial points if there is a linear mapping between coordinate spaces. When noise is added to the location of the fiducial points, the accuracy decreases but with moderate (50) numbers of fiducial points back propagation networks can achieve an accuracy the same as or better than individual fiducial points. A sigmoid activation function with no hidden layers may perform slightly better when there is moderate noise.

Back propagation networks accurately map between coordinate spaces which are rotated, translated, and linearly scaled in 3 dimensions.. A comparable point based image registration method developed by A.C. Evans et al using a linear least-squares technique showed an approximate 2.5-3.5mm 3-D error with simulated points with 5mm random noise in identification of 16 fiducial points [6]. While their error measurements are not directly comparable the 3-D error using ANN appears of similar magnitude.

The disadvantage to the ANN technique lies in identifying the multiple points which represent the same locations in both image or physical spaces. Further research is necessary to determine if there are artificial neural network techniques which would not require the identification of these fiducial points in the two coordinate spaces. Simply identifying groups of points, curves or surfaces that correspond in the two coordinate spaces may be an alternate approach.

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Interactive Control of Excitation for Real Time Magnetic Resonance Imaging

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I. INTRODUCTION

Advances in the design of magnetic resonance studies (e.g. Pauly 1989) have created a demand for a faster, more powerful prescription control. In particular, response modulated excitation (RME) defines a relaxivity-corrected specified volume in a single RF / gradient waveform pair in 3 milliseconds (Pearlman 1994). This has numerous real-time imaging applications, including continual imaging of locations (M-mode), velocity vectors (V-mode) and derived parameters such as blood pressure (P-mode) (Pearlman 1990, 1992, 1994). A striking new application is very small field of view imaging (65 micron resolution) inside large targets, without aliasing, saturation, or oversampling. In response to the demand for adaptive design created by these real-time capabilities, we have implemented a new level of control for NMR investigation - one that takes fundamental design descriptions as graphic input and automatically applies physics models dealing with spatial frequency trajectories to design and implement the pulse program in seconds on a Sparc 2 (Sun Microsystems, Inc., Mountain View, CA).

The usual design of NMR studies selects a model based on spatial frequency coverage of the target to be imaged (k-space trajectory), then a pulse program is coded by a physicist, and a few parameters are available for final adjustments. Our design takes model selection (k-trajectory and desired magnetization pattern) as input, and the pulse program is generated and compiled automatically. This makes fundamental redesign of the NMR study interactive, using a graphical interface.

II. METHODS

We implemented control of real time excitation in software on a Unix platform using a prototype echo-planar MR scanner (Siemens AG, Erlangen, Germany). The software is divided into three modules: (1) an input module which allows the user to specify the magnetization profile and k-space trajectory, (2) a calculation module which calculates the appropriate pulse sequence parameters (RF and gradient waveforms),

and (3) an output module which automatically creates a working pulse sequence in which the desired profile is excited.

Input module

The user interface for the input module is a Sun XWindow, as shown in Figure 1. The module allows input of the following user-defined parameters:

- Magnetization prescription, i.e.. the beam diameter, position, shape, and profile. For specification of the size and position, there is an optional graphical interface which allows the user to position and enlarge the beam by manipulation with the mouse. This more easily allows placement of the beam on a structure of interest, since it can be positioned relative to a scout image.
- Gradient trajectory's scale and path.
- T2 relaxivity of the area to be imaged, to allow for relaxivity correction in the RF waveforms.
- Excitation duration.

After making selections with the user interface, all the remaining tasks are completed automatically by the software.

Calculation module

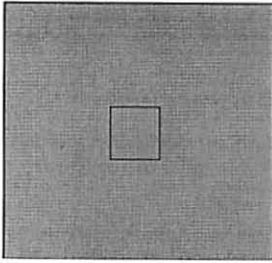
The calculation module consists of several components. First, given the path and scale of the gradient trajectory defined by the user, the calculation module first calculates the corresponding k-space trajectory by the integral:

$$M_{xy} = \int B(t) \exp(ikx - t / T2) dt$$

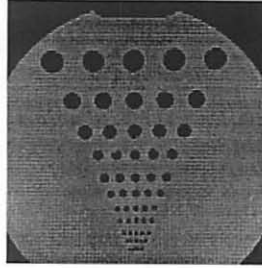
A useful trajectory for such an excitation is the rectilinear echo-planar trajectory, with continuous sinusoidal variation in one direction (K_x) and short blips in the other (K_y), as illustrated in Figure 2. This strategy limits spatial aliasing to the K_y direction, where it is isolated and removed by an analog filter. Both spiral and rectilinear trajectories are supported by the software, with the choice of "half fourier" excitation available for the rectilinear trajectory.

Given the shape and size of the prescription as defined by the user, the calculation module then determines the RF waveform that will perform the excitation. The result is $RF(k)$, the RF energy as a function of k-space. For a square profile, as in Figure 1, this would be a 2-dimensional sinc. For incorporation into the pulse sequence, this $RF(k)$ must be converted to a time series, $RF(t)$. The software now uses the calculated k-space trajectory, and $RF(k)$ is evaluated at the k-space points on the trajectory, as illustrated in Figure 3. Since each point along the trajectory corresponds a single instant in time, the evaluation gives the RF as a function of time.

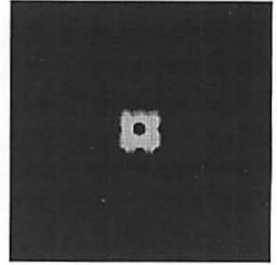
A. Input Module Dialog



B. Graphic Controller



C. Scout Image



D. RME Image

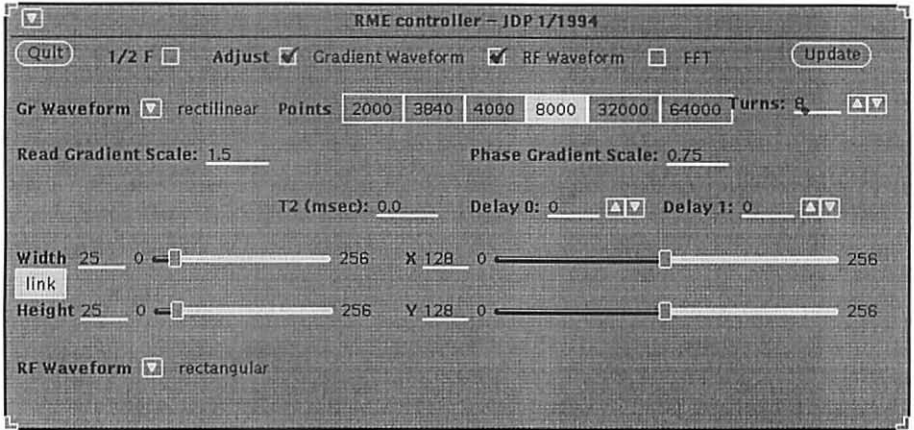


Figure 1. Input module controls. (A) The dialog with which the user enters the RME prescription parameters. (B) The graphics controller window, which provides the user with feedback on the size, shape, and position of the prescription. (C) The scout image used for positioning of the beam. (D) The final RME image, which matches the prescribed excitation.

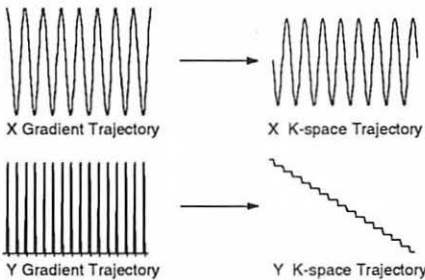


Figure 2. Rectilinear k-space trajectory formation. The sinusoidal X gradient trajectory produces a sinusoidal trajectory in k-space, while the train of Y gradient impulses produces steps in k-space. Together, the X and Y trajectories provide a 2-D rectilinear coverage of K-space.

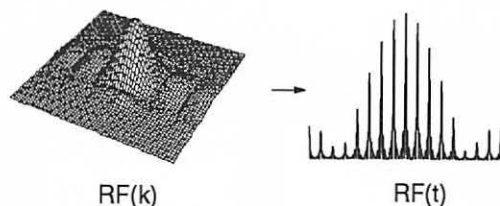


Figure 3. Time-based RF profile formation. The 2-D k-space sinc function is converted into an RF time series bases on the k-space trajectory.

A "real world" k-space trajectory has some regions of k-space covered very sparsely, and other more densely, depending on the size of the gradients and on the speed at which k-space is covered. The deposition of the RF energy in k-space is governed by this adequacy of coverage. The calculation module accounts for this by calculating the Jacobian for the change in parametric variable from k-space to time.

Since the NMR signal decays exponentially with time constant T_2 , a profile created with long excitation time ignoring relaxivity will be distorted. The calculation module corrects for this T_2 relaxivity, resulting in significantly better profiles.

Even after the prescription shape and size have been calculated, the beam may be repositioned. The calculation module determines phase roll in the RF that moves the beam appropriately and modifies the RF phase accordingly. For example, a flat phase leaves the beam centered while a phase rolling in tandem with one component of the k-trajectory moves the beam in the direction of that component.

Additionally, the calculation module displays a simulation of any desired profile, to facilitate the user's choice of parameters. To perform this simulation, the software regrid the RF time series onto a discrete k-space array. This array is then Fourier transformed and deconvolved to yield a simulated image, simultaneous with acquiring a real image.

Output module

Once the gradient and RF waveforms have been calculated, a pulse sequence is automatically edited to incorporate the changes and produce the desired magnetization profile. The output submodule calculates the appropriate refocusing lobes for the given k-space trajectory, allows visual computer-assisted pulse sequence editing, and precalculates effects for flow and other compensations.

III. RESULTS

We have tested our RME control by performing interactive modification of graphic prescriptions in small field of view (FOV) imaging. Figure 4 shows the results of interactive prescription changes for imaging a small central region inside a resolution water phantom.

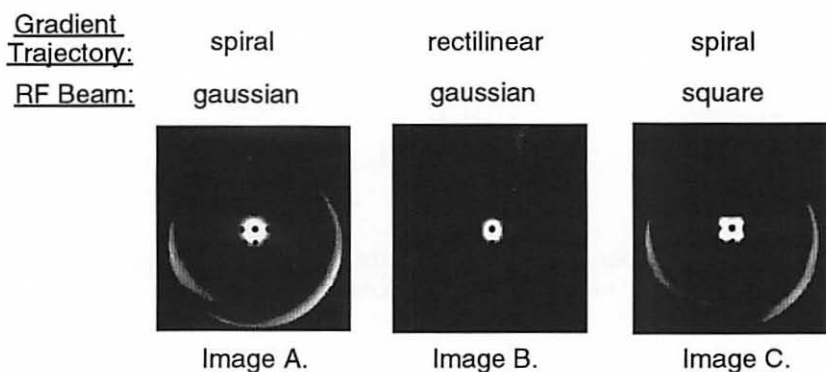


Figure 4. RME images of a resolution water phantom collected using different RF and gradient parameters, with a beam diameter of 25 mm. (A) Centered circular beam with gaussian profile; spiral gradient trajectory. (B) Centered circular beam with gaussian profile; rectilinear gradient trajectory. (C) Square beam with flat top; spiral gradient trajectory. The change from A to B and from B to C each required a rewriting of the pulse sequence, activated by simple graphics window prescriptions.

Normally, restriction of read-out to an area smaller than excitation results in aliasing of exels outside of the FOV into the FOV, as shown in Figure 5b. Restriction of the extent of excitation using RME, however, yields images with no such distortion, as shown in Figure 5c. Also apparent is an improvement in image quality using RME.

IV. DISCUSSION

Previous workers have developed control systems for some of the parameters involved in magnetic resonance imaging. Riederer (1984) developed an interface control for progressive update angiography. Pearlman (1990) previously developed an interface control program that allowed the user to direct a real time motion (M-mode) MRI examination. Hardy (1990) developed a graphics oriented user interface for cardiac examination. In the current study we have taken a user-supplied magnetization prescription and created from it a magnetization profile for real time MRI. Implementation of dynamic control of excitation has allowed us to limit excitation to prescribed 3-D regions using an interactive, graphical interface. This permits rapid exploration of fundamental pulse sequence design changes, such as specification of the k-trajectory and 2-D delimiting of the target zone.

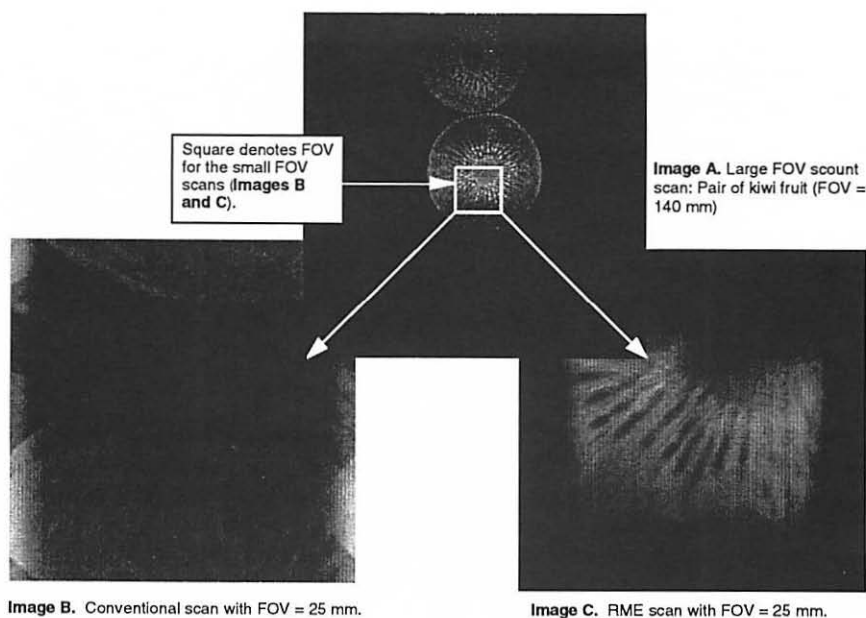


Figure 5. Images of a pair of kiwi fruit (A) obtained using small field of view conventional spin-echo imaging (B) versus RME imaging (C). The RME image not only shows an absence of aliasing artifact, but also demonstrates excellent image quality.

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FOCUS SESSION

Virtual Reality

Chair: Herbert H. Taylor

Virtual Reality Imaging of Human Anatomy

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I. ABSTRACT

We have applied virtual reality technology to medical imaging. Digital images acquired with helical computed tomography (CT) are used to create three-dimensional (3D) simulations of human anatomy. A patient is scanned using a GE HiSpeed Advantage CT scanner, image data is transferred to a Silicon Graphics Crimson VGXT computer workstation, and a "virtual patient" is generated using a customized version of IRIS *Explorer*™ software. Unlike conventional 3D medical imaging which usually provides only an external view of an object, our technique allows a physician to "fly" inside a hollow organ (airway, bowel, blood vessel) to examine internal detail.

II. INTRODUCTION

Virtual reality imaging is an emerging technology that promises to revolutionize medical imaging. Although it has been popularized in the public press as futuristic, virtual reality is currently used at our institution. As applied to medicine, the term "virtual reality" is perhaps a misnomer since actual patient data is used to construct the simulations. The term interactive 3D more accurately describes the technique but fails to capture the public's attention.

Virtual reality is the next evolutionary step in 3D imaging.¹ Two key ingredients have made virtual reality imaging possible in medicine: (1) realtime 3D rendering and (2) acquisition of anatomical volumes. Interactive 3D rendering is produced on specialized graphics workstations that are capable of rendering at rates faster than can be detected by the human eye. Virtual reality

surpasses conventional 3D medical imaging by allowing a physician to "get inside" the anatomy and explore it in a manner with which they are more familiar.

Cross-sectional imaging modalities such as spiral/helical CT, MRI, ultrasound, SPECT, and PET have created volume datasets which are necessary for creating these simulations. During the past decade, most 3D medical imaging was centered on neuroimaging and orthopedics: The reason for this is that the extremities and the head did not move with respiration. Helical/spiral CT has made 3D reconstruction in the thorax and the abdomen feasible by producing continuous volumes of data during single breath holds, thus eliminating respiratory motion artifact. Three-dimensional MRI and ultrasound hold promise for the future but are not readily available today. Nuclear medicine modalities including SPECT and PET lack spatial resolution but may find their niche in image fusion with CT and MRI.

Rather than approaching virtual reality as a technology looking for an application, we have defined real medical problems that benefit from the application of this technology. At our institution, we have concentrated on three clinical areas: (1) the tracheobronchial tree, (2) the gastrointestinal tract, and (3) the vascular system. Our virtual reality techniques could be applied easily to other anatomical regions.

II. MATERIALS AND METHODS

Virtual reality imaging consists of the following four steps:

1. Image acquisition
2. Volume formation
3. Image segmentation
4. Realtime 3D rendering

Image acquisition is performed using a GE HiSpeed Advantage Helical CT scanner (General Electric, Milwaukee, WI). For optimal simulations, helical CT scanning protocols are configured to the anatomical region of interest. For example in the vascular system, a bolus intravenous injection of iodinated contrast material (Isovue-370, Squibb Diagnostics, Princeton, NJ) is administered to opacify the vessels. Helical CT is performed during a single breath

hold acquisition using 5 mm x-ray beam collimation at 2:1 pitch. Images are retrospectively reconstructed at 1 mm intervals; as a result, isocubic voxels are produced by interpolating directly from the raw CT dataset. Similar protocols are applied to the tracheobronchial tree and to the gastrointestinal tract although in the latter case the bowel is distended with air.

Digital CT images are transferred from the CT scanner to a Crimson graphics workstation (Silicon Graphics, Inc., Mountain View, CA) via a fiberoptic network using file transfer protocols (FTP). Volume formation is simply the stacking of a series of digital images in computer memory. A typical CT exam through the abdomen might consist of up to four hundred 0.5 megabyte images. Currently it is not possible to generate realtime renderings with this amount of data. Therefore, we crop the x, y, z dimensions of the dataset and scale each 16 bit pixel to 8 bits. We use volumetric rendering software (*VoxelView*, VitalImages, Fairfield, IA) to edit the volume and to map the pixel values. Future development of parallel processing systems will make it possible to work directly with the original datasets.

Image segmentation and virtual reality simulation are performed using a general purpose volume visualization program, *IRIS Explorer™* (Silicon Graphics Inc., Mountain View, CA).² *Explorer's* segmentation scheme uses a simple thresholding method and a "marching cubes" algorithm to form an isosurface (a surface of equal voxel value) for an organ of interest.³ It is easy to extract the air-filled lumen of the airways from the thorax where the contrast difference between air and surrounding soft tissue is on the order of 1000:1, but it is much more difficult to extract lymph nodes from surrounding mediastinal tissues where the contrast difference is less than 2:1. Development of edge detection and region growing methods may solve this problem.

Explorer uses a surface rendering technique to visualize and manipulate the 3D data. *Explorer's* renderer has an unique feature that gives a user (physician) the ability to "fly" through the volume-of-data. This technique allows a physician to examine CT data in a way never before imagined. The direction and speed of flight are controlled with a mouse device. "Flying through the anatomy" is analogous to traveling through the human body in a tiny spaceship.

III. RESULTS

It is difficult to experience virtual reality within the printed format of this book since it relies upon visual feedback during the motion sequences. However, the following cases give a glimpse of what can be achieved. A note should be made that these images are black and white whereas the original color images add realism to the simulations.

The first case shows an airway from an external perspective demonstrating the trachea, aortic arch, and superior vena cava (Fig. 1A). The image sequence illustrates a flight into the trachea (Fig. 1B) and right mainstem bronchus (Fig. 1C).

The second case is an example of the colon. The colon is viewed from an external perspective revealing a catheter inserted into the rectum (Fig. 2A). Subsequent images detail a flight into the catheter (Fig. 2B) and through the rectum (Fig. 2C).

IV. CONCLUSION

We are using virtual reality technology in daily clinical practice. Virtual reality promises to revolutionize medical imaging by allowing physicians to analyze volumetric data (CT, MRI, US, SPECT, PET) in a more intuitive and thorough manner. Advances in parallel computer processing and improved image segmentation techniques will promote the success of virtual reality imaging.

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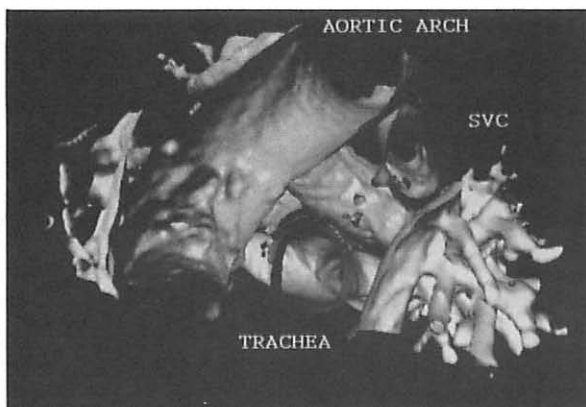


Figure 1A



Figure 1B



Figure 1C

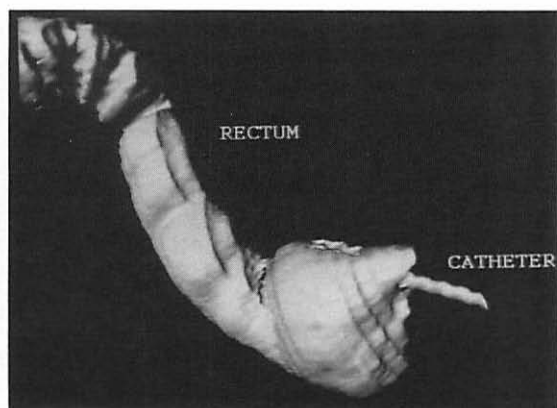


Figure 2A

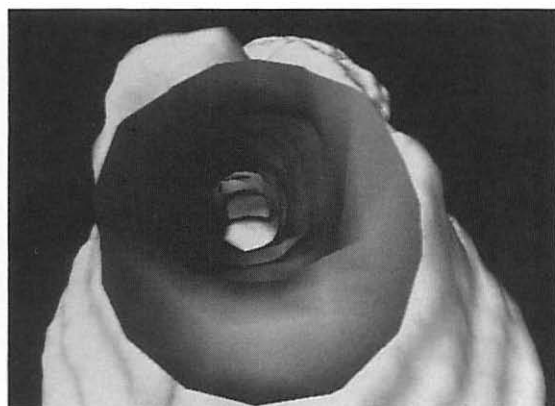


Figure 2B

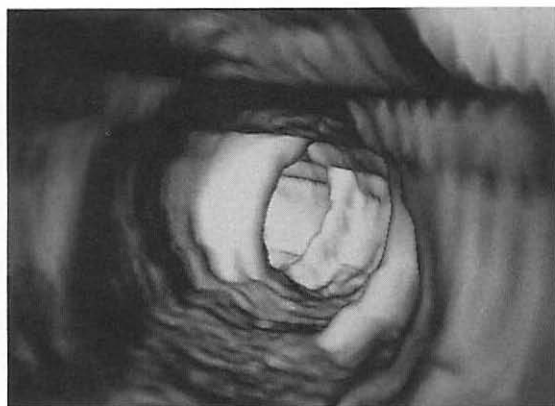


Figure 2C

Posters

Combined Approach: An Invariant Decision Tree Classifier (DTC) Using the MT Transform

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ABSTRACT

The MT-transform has the advantages of having uniform amplitude bounds, high speed and a simple hardware realization. Thus when a conventional classifier is used with an MT-feature vector, the classification process represents a computational load. In addition, these conventional classifiers suffer from many other drawbacks. In this paper, we describe the use of the MT-feature vector with the decision tree classifier (DTC), thus the recognition is invariant and the process is fast and simple. This is a combined approach, i.e., the process combines feature extraction, feature selection, and classification. In addition, experimental results show that a higher classification rate has been achieved with less than 20 percent from the feature vector.

Translation invariant transforms (TIT) are a valuable tool for feature extraction in pattern recognition. These transforms can characterize objects independent of their positions and orientation. The family of these transforms is infinite. Since this family is infinite a "best" transform could conceivably be selected for each different applications where an emphasis may be placed on specific properties such as speed, hardware realizations and/or memory requirements. It has been shown that the MT-transform has the advantage over any member in the translation invariant transform family of having a uniform amplitude bounds. In addition to its speed, its hardware realization is simple. The recognition of an unknown sample with n -dimensional feature vector is achieved by comparing the transform output of this feature vector with that of the model. This can be done by using the nearest mean classifier (in real-time pattern recognition). Thus, much of the gain one has achieved by using the MT-transform is lost due to the comparing process of the classifier. Moreover, these conventional classifiers suffer from the following drawbacks:

- 1) Only one possible combination of the pattern features is used in the classification
- 2) Each data sample has to be tested against all classes, which leads to a relative degree of inefficiency
- 3) The set of pattern features used in classification is not necessarily the optimum for all classes.

On the other hand, decision tree classifiers are characterized by the fact that an unknown sample can be classified into a class using one or several decision functions in a successive manner. This will lead to the following advantages:

- 1) A feature is calculated only when it is required for classification
- 2) Because the features are used conditionally, a feature which is unimportant, except for special cases, does not impact the efficiency and accuracy of decision in other cases.

In this paper, the output of the MT-transform, which is invariant under object rotation, translation, and scaling, is used with DTC rather than nearest mean classifier. This is a combined approach including feature extraction, feature selection and classification. We show the DTC obtained for classification of 4-class real world problem and compare the classification rates obtained from using the DTC against using the nearest mean classifier. This comparison shows that with only less than 20 percent of the feature vector we got a better classification rate in addition to speed and simplicity.

Computerized Three-Dimensional Reconstruction of the Conductive System of Heart

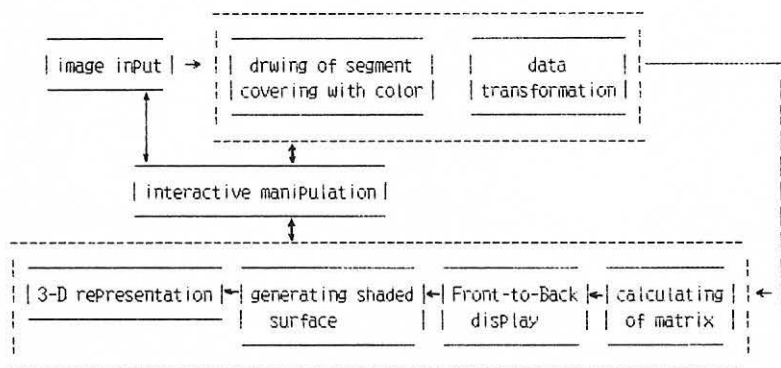
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The conductive tissue of heart is the center of its electro-physiological activities and is also important to the surgical correction of congenital heart malformations and acquired heart diseases. But the conductive tissue is so small that it is easily injured during operation. We used computer graphic techniques to model the three-dimensional reconstruction of the sino-atrial node and atrio-ventricular node of the normal heart as the first step.

The series of histological sections of the human S-A node were obtained by cutting them perpendicularly to the terminal crest, 71 of the 1245 sections were stained with phosphotungtic acid hematoxylin (PTAH); the series sections of A-V node were cut perpendicularly to the plane of atrio-ventricular septum, and 90 of 2190 sections were stained with PTAH. By division, interpolation, and generating shaded-surface display, we made a color 3-D model of the A-V node and the S-A node.

Working procedure of reconstruction



The results are satisfactory as the modes are very similar to the natural sample, the modes can be rotated or sectioned anywhere, and we can also show one or several parts of the models.

Models of the three-dimensional appearance of the human conductive system are usually not made because they are too time-consuming and costly. In this study, we present a new method to show the conductive system which is embedded in the muscle of the heart, and this study establish the basis of continuing the works on congenital heart disease.

Nonlinear Modulation Transfer Functions

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I. Introduction:

How can it be that an exposure that is ideal for conventional x rays is not ideal if the image is viewed on a monitor after digitization? If the digitization works better for lower exposure rates can a reduction in radiation dose be possible? What is the influence of filtering algorithms? The problem of answering these questions is reflected in the problem of understanding the physical characteristics of medical imaging systems.

Modulation transfer functions (MTF) are a powerful tool for the physical description of the image quality for medical imaging systems. Especially for the case of negligible image noise the image quality can in many cases be completely described using the MTF.

In the commonly used mathematical description of MTFs and their basic properties there are two main assumptions: Linearity and Spatial invariance.

It is well known, that in real systems these conditions are often not valid. If the spatial invariance condition is not fulfilled the MTF becomes a multidimensional scalar function. For the description of nonlinearity of the photographic process there exists heuristic stage models. However a mathematical description of the nonlinearity in imaging systems is missing.

Digital imaging systems however uses nonlinearity as basic properties of the imaging functions:

- look up tables are general nonlinear pixel to pixel modifications
- filters are nonlinear modifications where the modification of a pixel depends on the pixel more or less close to it.

Thus for the understanding of the properties and the capabilities of digital imaging systems a mathematical description of nonlinear modulation transfer functions is necessary.

II. Introducing nonlinearity into the mathematical description:

Commonly used properties of MTFs like that a sine wave pattern transforms itself into a sine wave pattern or that the MTF of chained imaging system is the product of the MTFs of its chain components, or the formulae from Coltmann are only valid for linear imaging systems.

To see how a sine wave pattern transforms by an imaging systems with slight nonlinearity, which i.e. may be a usefull description for the low density range for photographic film screen systems, we introduce a nonlinear term of second order:

A sinusoidal object density distribution $g(x)$ can be described as:

$$g(x) = 1 + k_0 \sin(2\pi\nu x) \quad (1)$$

In a linear system a single "line" of object intensity $g(x)$ and width Δx will be imaged to a point x' in the vicinity of x with the image intensity

$$g(x)L(x' - x)\Delta x$$

Where $L(x' - x)$ is the even (we assume spatial invariance) normalized line function of the system. Supposing that the system possesses a slight nonlinearity that does not affect the shape of a line image, than the image intensity of the line may be described as:

$$(g(x) + \alpha g(x)^2)L(x' - x)\Delta x$$

where α is a small constant parameter.

The total image $b(x')$ is then the integration over all line images:

$$b(x') = \int_{-\infty}^{\infty} (g(x) + \alpha g^2(x)) L(x' - x) dx$$

Introducing $g(x)$ from equation (1) the calculation leads to

$$b(x') = (1 + \alpha) + k_0(\eta_l + 2\alpha) \sin(2\pi\nu x) + \alpha k_0^2(1 + \eta_{nl} \sin^2(2\pi\nu x))$$

with $\eta_l = |\int_{-\infty}^{\infty} L(x)e^{i2\pi\nu x}|$ and $\eta_{nl} = 1 - \int_{-\infty}^{\infty} L(x) \cos^2(2\pi\nu x)$. Both modification factors η_l, η_{nl} are in the range between 0 and 1.

III. Discussion:

The term linear in k_0 shows that the quotient of the image contrast and the object contrast can now have values greater than 1. This is a theoretical background that nonlinearity can even be an advantage for saving underexposed images. The term of second order in k_0 shows that higher frequencies terms appear in nonlinear systems. The image of a sine wave pattern is no longer a sine wave pattern of same frequency, except if $L(x)$ is the δ -function ($\Rightarrow \eta_{nl} = 0$). The remaining term αk_0^2 recommends the use of a negative α for optimizing systems for low contrast imaging (negative curvature of the grey value look up table function), and a positive α for optimizing systems for high contrast imaging.

Scanning Resolution for Slide Making

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Purpose: To determine an optimal scanning resolution to be used with the Polaroid CI5000S.

Methods and Materials: 15 ASMPTE test patterns were laser printed to a 14 x 17 inch film. The test pattern was scanned using a Umax UC840 scanner (800 dpi) with a transparency adapter (firmware ver. 1.4, Twain driver ver. 1.03). The 1 x 1.5 aspect ratio, as found on 35 mm slides, was maintained with all images scanned at 100, 150, 200, 250, 300, 350, 400 dots per inch (dpi) without software enhancement or correction. Image sizes 1 x 1.5 inches, 2 x 3 inches, 4 x 6 inches and 5.5 x 8.25 inches were obtained. The images were TIF and BMP types. The TIF images were printed to the slide maker through PC DOS using ImagePrint software version 1.41. The TIF and BMP images were printed through Windows using Freelance ver. 2.1, for comparison of the resolution by the two software systems and image types. The slides were then projected in an auditorium on a 12 x 12 foot screen. Four experienced radiology residents not involved with the project were asked to score all images, determine resolution by comparing line pairs and then select the best of the 84 images.

Results: The DOS and windows results were similar. There was no difference in the windows TIF and BMP formats. The test pattern showed improvement up to 400 dpi on the 1 x 1.5 inch image, 350 dpi on the 2 x 3 inch, 250 dpi on the 4 x 6 inch and 200 dpi on the 6 x 9 inch scanned image sizes.

Conclusion: There is no advantage in scanning images for slide making above 250 dpi unless the image sizes are small at which time 400 dpi will show improvement.

Control of Patient Exposure in Computed Radiography

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Purpose

Using a computed radiography (CR) system in intensive care units, it is important to have a mechanism to control patient doses retrospectively. This special need is caused by the absence of phototiming, difficult exposure conditions and the problem to get information about the dose used for this image. In conventional radiography over- and underexposures are directly visible. CR behaves differently. Underexposure results in increasing image noise, overexposure turns out in increased image quality. For this reason it is necessary to control exposure dose to stop a possible migration to higher doses. In conventional film screen systems the user is 'punished' by an unusable image due to overexposure, in CR he is 'rewarded' by better image quality. Most of the CR systems have no direct access to the applied dose for the radiologists. This concludes in a demand for a mechanism to control applied exposure dose using CR-systems for intensive care units.

Material and Methods

In paediatric intensive care unit a CR system (Digiscan, Siemens) was used in the last four years. Out of the image data and the relationship between dose and gray value it is possible to calculate the dose at the image plate using the formula:

$$\text{Dose} = \text{const} / \left(S \text{ factor} * \exp_{10} \left(L \text{ factor} * \frac{I - 511}{1024} \right) \right) \quad (1)$$

where the S factor is the intensifying factor, the L factor is the dose range taken into account, both are printed on the film. I is the gray value measured at the workstation and the constant depends on kVp and screen type, but is about 1000.

This method to determine applied dose gives a tool for comparison and control. Patient doses were calculated for five different time intervalls and compared with values for film-screen combinations. The dose was measured in the right and left lung field as mean of a region of interest. Artificial structures as catheters and clips etc. were excluded. The region of interest is in a similar position as the right field of the phototimer.

Results

The first value was measured for a conventional film screen system with a speed of 250. The mean value for the dose reaching the screen in the region of the right lung is about 7.6 μGy corresponding to a mean optical density of 1.5. Introducing CR, the first three months (digi1) gives a mean value of about 6.2 μGy . In the second three months (digi2) mean dose increased to a value of about 11.1 μGy , caused by better image quality using higher doses. This result causes a decrease of dose to a value of 7.6 μGy (digi3). Then a 0.2 mm Cu filter was installed, giving a reduction of the dose to 3.1 μGy (digi4). One year later there was no significant difference in dose (digi5) (figure 1). It is necessary to use formula (1) to calculate the dose, the use of the S factor only will lead to errors. For many samples the results are similar, but some of them are quite different. This is caused by variations of the reading algorithm of the CR system.

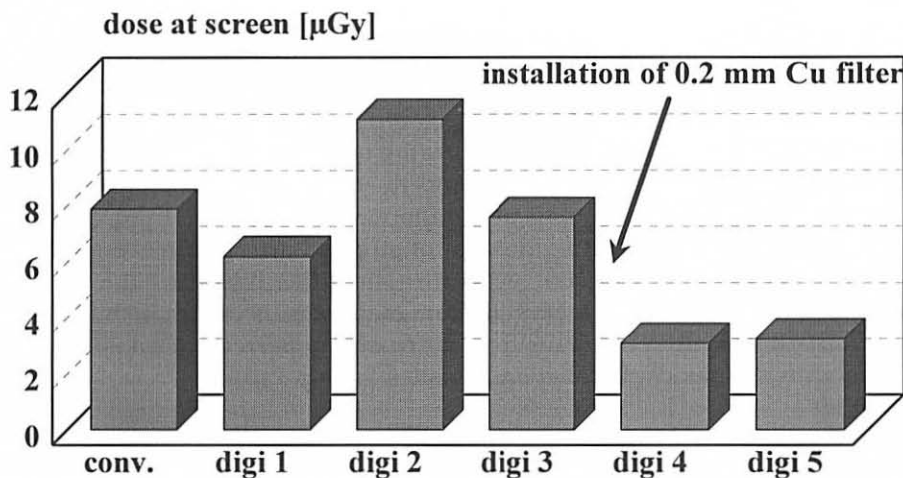


Fig. 1: Mean dose for different imaging systems and time intervals. Before the CR-system was installed, mean dose was determined (conv). After the installation five different time intervals were analyzed to get the applied dose, respectively.

Conclusion

Using a CR system it is possible to evaluate patient doses retrospectively. This procedure can be applied for optimization of patient dose. Due to the absence of a control mechanism for over- and underexposure it is necessary to check applied dose in intensive care units regularly. The method presented herein resolves this problem.

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Noninvasive *In Vivo* Detection of Early Atheroma Changes Within Human Arteries

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Introduction

This abstract describes magnetic resonance spectroscopy (MRS) of atheromatous lipid mixtures and *in vivo* spectra obtained by localized (1cc volume) MRS from carotid arteries in human volunteers.

Atherosclerosis, normally undetectable until its advanced stages, is responsible for upwards of 550,000 deaths *per annum* in the United States. We seek to improve early detection and treatment of atherosclerosis. These stages are marked by a small accumulation of atheroma lipid, a liquid-crystalline mixture [1] inside the wall of stressed arteries. It is known that atherosclerosis has distinctive signatures in MRS [2] However, a major difficulty with noninvasive MRS of human arteries is distinguishing signal from atheroma within the walls from surrounding perivascular fat, a normal tissue with similar chemical characteristics and spectrum.

Methods

Proton spectra from fresh human plaques, obtained post-arterectomy, were analyzed at 361.1 MHz and 37°C; synthetic chemical analogs were analyzed at 360.2 MHz over temperatures ranging from 23°C to 65°C in 3°C increments. A Bruker AM360 magnet (Billerica, MA) was employed. Magic-angle spinning (MAS) technique at 10kHz was used to reinstall the broadened MRS signatures from samples in solid-like states.

In vivo spectroscopy was performed on a Siemens 1.5T echo planar whole body scanner (Siemens Medical Systems). A double-CHESS water suppression sequence was used to visualize the *in vivo* spectra. We developed GUI software (InSpect™) on a Sun SPARCstation (Mountain View, CA) for analysis and display of MRS data and to determine the fractional amount of atheroma lipid present in mixed atheroma-fat samples. InSpect provides interactive mathematical modeling, graphing and statistical tools.

Results and Discussion

Spectra from human plaque (figure 1a) and synthetic atheroma analogs (16.5% palmitic, 45.1% oleic, 38.4% linoleic cholesteryl ester with varying amounts of triolein), shown in figure 1b, indicate transitions between solid-like and liquid-like states. Note in figure 1b that the major T2 step change

occurs at lower temperature with increasing triolein concentration. This may indicate that triglycerides play a role in regulation of physical-state changes for atheromatous lipid mixtures.

Figure 2 shows *in vivo* ^1H localized spectra obtained at the carotid bifurcation from a volunteer with high blood-cholesterol levels. Although resonances are slightly broader than those obtained from synthetic mixture, the essential MRS signatures can be detected. Localized *in vivo* MRS of atherosclerosis is in its early stages and is the subject of on-going investigation.

We have shown that ^1H spectroscopy is effective for studying the physical state of atherosclerotic lipid mixtures, and that MAS ^1H will reinstall high resolution to the spectra of solid-like states, allowing study of the structures of lipid mixtures most relevant to deposition. With water suppression techniques it is possible to obtain *in vivo* magnetic resonance spectra for study of atherosclerosis.

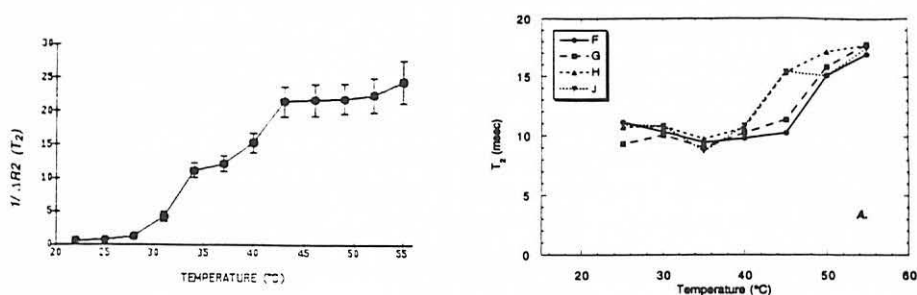


Figure 1a. (left) Spectrum from human atherosclerotic plaque. 1b. (right) Spectra from synthetic analog; F,G,H and J represent 4.4, 7.9, 9.5 and 10.8% triolein as percentage of total cholesteryl esters.

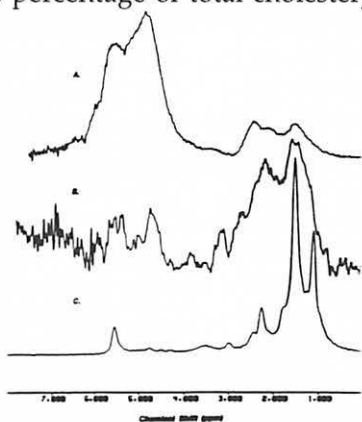


Figure 2. *In vivo* ^1H spectra. Trace A: STEAM-localized spectrum without water suppression, B: double-CHES water suppression, C: synthetic mixture.

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Labeling of MR Brain Images Using a Boolean Neural Network

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ABSTRACT

The labeling of tissues in MR brain images is an important stage in the potential automatic analysis of these images. This labeling can yield valuable information concerning structure and pathology, detect abnormalities and can facilitate an imaging-based diagnosis. In this paper, a method for MR brain image labeling using a Constraint Satisfying Boolean Neural Network (CSBNN) is described. The experimental results on MR brain images show that the CSBNN can perform the MR image labeling much faster than traditional methods and other neural networks. Since the Boolean Neural Network (BNN) provides immunity to noise, robustness and is easy to implement compared to other networks used for the same purpose, this method offers a feasible alternative to existing techniques for medical image labeling.

I. INTRODUCTION

MR image labeling is acknowledged as an important process in the potential automatic analysis of these images. This labeling can yield valuable information concerning structure and pathology, detect abnormalities and can facilitate an imaging-based diagnosis. During the past years, a host of labeling strategies have been proposed.¹

The analysis of medical images is a high-level vision process. It is based on image-based knowledge representation and manipulation. The goal of our labeling method is to assign a set of labels to a number of segmented regions within a MR brain image. It is assumed that this labeling procedure operates on a segmented MR brain image of a known structure.

Recently some methods of image labeling using neural networks have been proposed.² This is because the traditional methods for image labeling are too slow. Due to parallel processing, neural networks are faster than traditional methods. In this paper, we will present a novel method for image labeling using a BNN^{3,4}. The advantages of BNN include a single training sweep, guaranteed convergence and simple neuron architecture. Since the BNN provides immunity to noise, robustness and is easy to implement compared to other networks used for the same purpose, this method offers a fast, feasible and reliable alternative to existing techniques for medical image labeling.

II. PROBLEM DEFINITION AND ITS FORMULATION USING A BNN

The image labeling problem can be stated as follows:

Assuming that an image is segmented into n regions, let $R = \{r_1, r_2, \dots, r_n\}$ denote the set of regions in that image. Let $L = \{l_1, l_2, \dots, l_m\}$ denote the m labels of the regions in the image, where $m \leq n$. The image labeling problem involves the consistent assignment of the labels to the different regions in the image.

An exhaustive enumeration of the unconstrained labeling of these regions yields m^n possibilities. This number can be very large if n or/and m are large. This problem is a constraint satisfaction problem and has been identified to be NP-complete. A consistent labeling is possible after the satisfaction of the constraints. The constraints involved are :

1. Single Label Constraint : Each region has exactly one label.
2. Region Adjacency Constraints : Some regions in the segmented image maybe adjacent to each other. In that case, two regions that are adjacent cannot have same labels.
3. Label Adjacency Constraints : Two labels may be known to be adjacent to each other.
4. Region Property Constraints : These consist of known facts and relations concerning image features like pixel intensity and region membership, region location, shape and volumetric properties, etc.

The image labeling problem can be mapped to the domain of the BNN. The resulting network is called the Constraint Satisfying Boolean Neural Network (CSBNN). The CSBNN consists of a CSBNN neuron array, a Control Logic Block and a Label and Region Property Constraint Checker (LRPCC). In the CSBNN neuron array shown in Fig. 1, each neuron represents the pairwise combination of a region and a label. Thus, for a n -region, m -label problem, there will be a total of $n \times m$ neurons in the neuron array. The neuron array enforces the single label and region adjacency constraints. The label adjacency constraints and the region property constraints are enforced using the LRPCC. The procedure for solving the labeling problem with a CSBNN is as follows:

1. Construct the network as shown in Fig. 1. Set the horizontal weights as -1 to satisfy the single label constraint. Set the vertical weights to -1 for adjacent regions and 0 for non-adjacent regions. The ROAs of all neurons are set to 0 and thresholds are set to 1.
2. Input a random initial state to the neuron array.
3. Generate the corresponding output of the neuron array.
4. The output of the neuron array is passed to the LRPCC which enforces the region property constraints and label adjacency constraints.
If the LRPCC signals a consistent state then that state represents the desired labeling and the procedure terminates.
Else the Control Logic Block uses a shift technique to generate the next state to be input to the neuron array of the network. Go to step 3.

III. RESULTS

The above network was simulated with different MR brain images. The simulations converged to valid labeling in a fraction of a second. The CSBNN was used on the MR brain image (Fig. 2) to label it. The labeling results are shown in Fig. 3.

IV. CONCLUSIONS

Labeling of MR brain images has been successfully accomplished using the CSBNN architecture. The results are available in a fraction of a second. Since the BNN provides immunity to noise, robustness and is easy to implement compared to other networks used for the same purpose, this method offers a fast, feasible and reliable alternative to existing techniques for medical image labeling.

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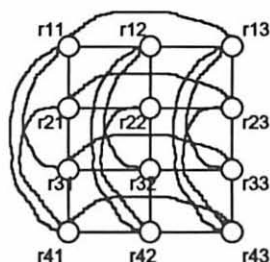


Fig. 1 : CSBNN neuron array showing the horizontal and vertical interconnections

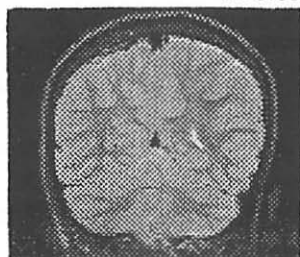


Fig. 2 : Original MR brain image.



Fig. 3 : Labeled MR brain image

Automated Speech Recognition Based Radiology Reporting for the Large Teaching Hospital: A Wish List

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While Automated Speech Recognition (ASR) radiology reporting is gaining wider acceptance among government and community hospital based practices, its penetration into large teaching hospitals has been significantly slower. Although economic factors are expected to drive large institutions towards ASR based reporting, a number of software advances are needed to meet the unique demands of these institutions. The factors that make teaching hospital based radiology departments unique include:

- They generally tend to have a large pool of highly subspecialized attending radiologists.
- Most subspecialists tend to read within their subspecialty, with occasional cross reading.
- There is an ever changing pool of residents requiring observation and review.
- They tend to be geographically spread out over multiple wings, floors and buildings.

In order to increase ASR acceptance in large teaching hospitals, we have compiled a "wish list" of desirable features:

- Users should be able to modify portions of their personal knowledge base (KB) while continuing to use a centralized, standardized version. This can be achieved by incorporating object oriented technology, such as inheritance and polymorphism.
- Knowledge base design should allow users to choose among various sub-bases for each subspecialty. For example, a chest radiologist might want to use a rudimentary bone radiology KB.
- Special features are needed to allow observation and review of resident reporting. Sites should have the option to store reports locally within the dictation system for later review.
- To facilitate acceptance and training, management features should be created to allow advisors to view how each individual user, or group of users, works within the system. This can make dynamic training, recommendations and system modifications possible.
- The geographic needs of the large teaching hospital should be addressed. Networking technology will allow any authorized user to access a single personal KB and voice profile regardless of his/her location within the department.

Since its introduction in the mid-1980's, automated speech recognition based Radiology reporting has seen tremendous growth. As medicine faces new challenges, we are confident that software vendors will continue to make the advances in technology necessary to increase productivity while decreasing costs. This in turn will help to bring the many benefits of ASR reporting to large teaching hospitals.

HIS, RIS and Modality Integration in Osaka University Hospital

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1. INTRODUCTION

Osaka University hospital moved to the new building and opened in September 1993. We named the new hospital "Intelligent hospital". We think the information system will effectively operate the flows of materials and informations of patients and workers and will give us a comfortable circumstances. Radiology Information System and PACS are the parts of this information system. But PACS is not installed yet, we will install the PACS step by step after our RIS functioned completely.

2. MATERIALS AND METHODS

Our hospital is a university hospital and works as a central hospital in Osaka area in Japan. Our hospital has 1,100 beds and over 2000 hospital staffs are working. Average number of outpatients is 2500.

We investigated the flow of radiological examination orders, X-ray films, and diagnostic reports in the present film-based system, and estimated the volume of them at each step of the flow. After that, with these volume in the film-based system, we estimated the data volume in digital PACS which would satisfy the requirements for our new hospital.

3. RESULTS

RIS contained the following systems.

1) Order entry system for radiological examination

The radiological examination order consisted of various data. The basic information is input by the clerks. The patient state informations are input by physicians or nurses at every occasions. The examination order information must be input by the physician. In our system physician must input clinical history, diagnosis and purpose of the examination.

2) Scheduling system of radiological examination

We prepared three types of scheduling system. 1) Emergent examination order is sent from HIS to RIS directly. 2) In the open reservation system, physician can select the vacant examination time. The examination order and date are transferred to RIS at same time. 3) In the closed reservation system, physician input only the order and the order is transferred to RIS. Radiologist reads the order and selects the adequate time and examination room. That information returns to HIS and the physician can see it.

3) Radiological examination assistant system

We made several assistant system for examination. When the patient come to our office, the clerk inputs patient's ID by the card reader. System shows the examination name, room and time of the patient. The clerk checks the time and the room of examination and explains it to the patient. System make receipt No. automatically. System displays the patient receipt number at the entrance of examination room to inform the correct examination room to patients. We select the patient from the list of waiting patients on the terminal of each examination room. And we can see examination name, purpose, clinical Diagnosis, history and the patient state also. And we can see the reports of previous examinations. After the end of examination, we input the number of films and drugs into the terminal of RIS. These data are transferred to HIS and the calculation will have finished when the patient goes to the accounting section.

4) RIS-FCR-Controller Connection

We made the new system at plain radiography section. We connected RIS, FCR and X-ray controller. After we select a patient from the list of waiting patients on the RIS terminal. RIS send the order data to FCR terminal. It has a table listed exposure condition for each examination. So it sends the preset exposure condition to the controller and scanning and processing condition to the FCR scanner. We can change the exposure condition afterwards. After exposure the actual exposure condition are transferred to RIS terminal and stored with examination data.

5) RIS-Handy terminal Integration

We made another new system for the portable exposure system. We set 2 FCR scanners in the wards and connected to the laser printer in the radiology department by the optical fiber network. In the radiology department, we transferred the portable examination order from the RIS terminal to the handy terminal. Technician goes to the ward, exposes and let the handy terminal read the bar code of the imaging plate in order to match the image and examination order. Afterwards the handy terminal is set to the scanner in the ward and scans the imaging plates. The image data with examination order from the handy terminal are transferred to the laser printer in the radiology department.

6) Reporting system

Our hospital opened in September the 1st this year. In these 2 months we input 7101 reports to RIS terminal. Our reporting system has 2 types of assistant system. One is to make sentences by selecting the words. The other is to select the patterns of sentences. And we have 2 types of storing. Temporally storing is storing only in the RIS and report are not transferred to HIS. It is useful to train residents to make reports.

4. CONCLUSIONS

Six months after opening, the reduced numbers of staffs are taking more examinations than the previous hospital. We think the introduction of RIS was effective.

Three Dimensional Dissection View of the Urinary Bladder

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Objective

The objective of this study was to visualize pathologies of the urinary bladder and their extension 3-dimensionally and compare its advantage as a diagnostic tool with existing modalities.

Methods

Nine cases of urinary bladder cancer were scanned during a single breath-holding period with a Toshiba Helical CT scanner(TCT-900S/Super HELIX). All cases were scanned in the prone position except for two cases which were scanned in both supine and prone position. Urinary bladder were evacuated their contents and then filled with air before scanning. The acquisition consisted of about 30 contiguous 360-degree tube rotation. Collimation was set at 2mm, and the table speed at 2mm/sec. Examinations were performed with 120kV and, 150mA or 200mA. Interpolation was made from the data of 180-degree tube rotation. Multiple axial images were reconstructed at 0.5-mm or 1-mm increments and transferred to a SUN Workstation through an ethernet network for three dimensional reconstruction of images using a software named Xtension from C-max. Multiple pairs of half cut sections were made by making a longitudinal or a horizontal incision on one wall and pulling apart the flaps to reveal the interior for better visual perception. The quality of the reconstructed images depended on the dexterity of selecting the appropriate threshold levels of the tissue desired to be viewed. Initially we adopted the conventional values that were hard coded in the software by the manufacturer. But since we were interested in viewing the minute lesions of soft tissue growth we experimented on different threshold levels. We calculated the values of the threshold of the CT images using a densitometer and

applied them directly on to the 3D images. From here we obtained the spacing of the threshold of the different tissues. Next by altering the values depending on the region of interest an optimum data of the tissue threshold was selected for the experiment. Since we focused on the urinary bladder we subtracted the adjoining organs as much as possible by changing the selected threshold to some extent, but took care not to diminish the visualization of the ROI.

Discussion

Longitudinal or horizontal cut sections of the urinary bladder were made as in a simulated surgical cut and the interior morphology was displayed along with the pathology. The 3D lesion could detect the severity and extension of the pathology on the visceral mucosa. The color hues created using the tissue classification module in the 3D could differentiate minute changes in the lesion from that of the normal mucosa suggesting the extent of the pathology. The margins of the lesion and the elevations made within it could be identified. It was difficult to determine the lesion margins in the case of the diffuse superficial tumor but was very distinct in the elevated tumors. The margins indicate only the circumferential extension of the lesion on the inner surface of the bladder. But to know the depth of the invasion the 3D images have to be correlated with axial CT sections. Depending on the cut section and patient position the urethral orifice and trigone could be seen in most of the cases, but it was not possible to see the opening of the ureters in any of the reconstructed images directly. But by identifying the trigone an approximation of the position of the ureteral openings could be made.

Conclusion

Horizontal cut section and the prone position of the patient offers better chances to see the urethral orifice. The detailed outline from the 3D profile, the minute distinction between abnormal and normal tissue and 3D dissection views were an added advantage over the existing procedures found in present modalities.

Networking and Image Processing at the Biomedical Imaging Center, University of Tennessee Medical Center

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The Biomedical Imaging Center (BIC) of the University of Tennessee Medical Center at Knoxville provides support for the digital imaging facilities of the Department of Radiology. BIC comprises PET (Positron Emission Tomography), MRI (Magnetic Resonance Imaging), CT (Computed Tomography), Nuclear Medicine and an Image Processing Laboratory (IPL).

The PET Center houses two CTI/Siemens (Knoxville, TN) ECAT positron tomography scanners, a 15-slice ECAT 931 controlled by a DEC micro-VAX II computer (Digital Equipment Corp., Maynard MA) and a 47-slice ECAT EXACT Model 921 controlled by a Sun IPX (Sun Microsystems Inc, Mountain View CA) workstation. The computers in PET are connected by optical fiber (Sun) or Ethernet (microVAX) to other machines in BIC.

The MRI facility houses two Elscint (Haifa, Israel) 2 Tesla GYREX MRI scanners controlled by PDP 11/84 computers that are connected by Ethernet to the BIC network. CT images are produced on three machines, - a GE (General Electric, Milwaukee WI) HiLight Advantage, a GE HiSpeed Advantage and a GE 9800. The three CT units are connected with Ethernet to a remote display console and to the main BIC network.

Nuclear Medicine houses nine cameras interconnected with Ethernet (using unshielded twisted pair wiring) and joined to the Image Processing Laboratory with optical fiber. There are four Adac/Pegasys SPECT units (Adac Laboratories, Milpitas CA) controlled by Sun workstations, three LFOV cameras driven by PDP11 computers and a SFOV mobile unit controlled by an 80386 unit. A MITA PC (Adac Labs.) transfers images from the SFOV camera, and CENTOR software from Adac is used to transfer images from the PDP11 units to the Sun workstations. In this manner images can be viewed at any Pegasys workstation in Nuclear Medicine and in the IPL.

The Image Processing Laboratory supports post-processing of biomedical images. The lab houses a Sun 4/690MP file server, two additional Sun workstations as

well as a Macintosh (Apple Computer Inc., Cupertino CA) and three personal computers. Additional Sun workstations, personal computer and Macs are housed in adjacent offices, and all interconnected by optical fiber (Suns) or Ethernet (Macintosh, PC). The IPL machines communicate via optical fiber with the University of Tennessee at Knoxville campus and thence to wide area networks. In the IPL we are able to obtain and display images from each of the four modalities - CT, PET, MR and SPECT.

Current projects in the IPL include:

- Three dimensional rendering and display of images using Analyze and IDL software. Three dimensional rendering, utilizing both surface and transparency views, has been used particularly with PET neurology studies. Software has been written to combine two separate renderings into one image set.
- Coregistration of anatomic (CT and MR) images with functional (PET and SPECT) images. Some work has been done with registration of PET and MRI scans of heads and we are now working with pelvic registration to supplement ovarian cancer studies.
- Development of a standard file format for working with images from any modality. Images will be converted to and from this format for any of the four modalities. All utilities for rendering, coregistration, etc. will be rewritten to work with this image format.
- Development of appropriate utilities and database tools to support fast and efficient archiving and retrieval of clinical images, with optional compression of dynamic images. We are currently concentrating on PET but may extend the work to other areas.
- Upgrading networking to permit efficient file transfer as needed while keeping network traffic to a minimum. We also need to combine the hospital's IPX (Novell) network with the BIC network (TCP/IP) so that users are able to view images and simultaneously access the department's scheduling system and the hospital's Patient Care System database.

Walk Through MRI Technique

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Introduction

This work has been developed from our experience in using CAI (Computer-aided Instruction) to teach new technique for radiologist [1]. Our assumption is that the user knows little or nothing about how MRI works, and we present an overview, basic physics principles, and how clinical MRI is carried out [2]. The purpose of our project is to develop an interactive hypermedia radiologic teaching tool capable of effectively integrating clinical information into a concise program.

Materials and Methods

The computer configuration used for "Walk through MRI" includes a Macintosh IIfx (Apple Computer, Cupertino, CA) with 8 megabytes of random access memory (RAM) and an 80-megabytes internal disk. The Macintosh software used to design the program comes under two categories: multimedia software, image processing software. The first one is SuperCard 1.6 (Silicon Beach Software, San Diego CA), an interactive hypermedia program which is user-friendly, allowing programming through scripts for the nonexpert user [3]. SuperCard integrates graphics (images), sound, video, and text. To transfer MRI images to within the SuperCard program we use a CCD scanner (Umax), with subsequent image manipulation within Adobe Photoshop 2.5 (Adobe Systems, Mountain View, CA). The Informatics laboratory of the Treviso Radiographer School has been used to make the concerned personnel executed the training; the Laboratory is equipped with four Macintosh LC with 4 MB of RAM and an 80-megabytes internal disk, and one Macintosh IIfx with 16 MB of RAM and an 160-megabytes internal disk.

The program "Walk through MRI" consists of four parts: the general principles, the device, the pulse sequences, and clinical cases. In the general principles the MRI technique is described both in its general aspects and in its physical aspects. The physical part has been carefully made highly didactic, and to do so are used all the instruments offered by the multimedia program such as graphics, flow charts, animations. The aim of the part referred to the device is to offer a method of learning all procedures without using any operation manual. In the third part the pulse sequences have been accurately described because of their fundamental role in forming the MR images. To understand this part better, it has been supplemented with a wide survey of

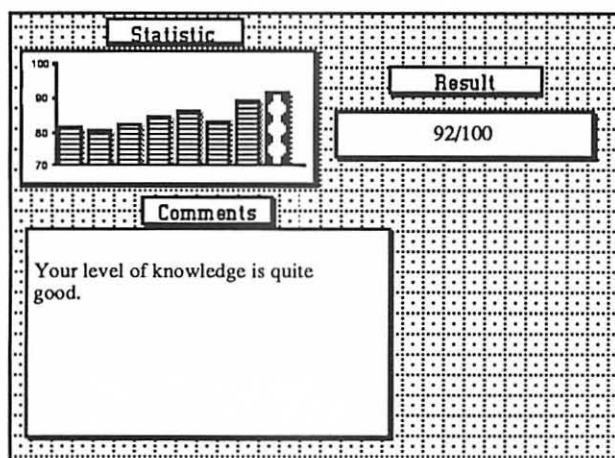


Figure 1: comment card of self-evaluation

images. Finally, the last part is mainly dedicated to radiologists, while the chapter is accompanied by a series of easy exercises. Each section of the program is equipped with tests to check the learner level of knowledge. The self-assessment [4] is made as follows: the learner answers a series of questions which are automatically evaluated. At the end of the test, according to the answers, a comment card (figure 1) is given to judge the level of knowledge and, if it is

necessary, to suggest how fill up the gaps. On the above mentioned card the comment is integrated by a graphic carrying the user's last ten results and the marks in hundredths. If the knowledge has to be improved some buttons appear and, if they are clicked on, they send back to the section containing the matter to study in detail.

Results and Conclusions

The programme helps the user use correctly and in a short time the machine. It can be considered to be an immediate reference to any difficulty besides. It is important to underline that it is an open programme where every change concerning our machine (MR 2200 by GEPIN-Rome-Italy) can be entered.

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Walk Through Computed Radiography (CR) Technique

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Introduction

The four-year daily use of CR has proved that the impact of such technique may be traumatic if effective strategies are not studied to bring up to date both physicians and radiographers. The three-year experience in using computer assisted education (CAE) in the Radiographers School of Treviso General Hospital [1] has suggested the idea of carrying out a multimedia program that supply the necessary informations to use CR correctly, and that meets the following fundamental requirements: it has to be easy to use, to be interactive, to enable learners to train autonomously [2].

Materials and Methods

The program SuperCard 1.6 (Silicon Beach Software, San Diego CA) has been chosen as personal software toolkit to perform the project. Infact it offers a wide range of opportunities to manipulate radiographic images and it helps carry out applications of easy use, thanks to the available powerful editing environment which make it suitable to develop multimedia programs.

The program "Walk through CR" can run on any Macintosh computer (Apple Computer, Cupertino, CA) with at least 8 megabytes of random access memory (RAM), an 80-megabytes internal disk, a 13-inch RGB monitor, and with a graphic card which allow to visualise at least 256 colours or grey levels. To digitalize the radiographic images has been used a CCD scanner (UMAX) with a spatial resolution up to 1200 dpi. The Informatics laboratory of the Treviso Radiographer School has been used to make the concerned personnel executed the training; the Laboratory is equipped with four Macintosh LC with 4 MB of RAM and an 80-megabytes internal disk, and one Macintosh IIfx with 16 MB of RAM and an 160-megabytes internal disk. The program "Walk through CR" consists of four parts: the general principles, the device, the image reading, and the image enhancement. In the general principles the CR technique is described both in its general aspects and in its physical aspects. The physical part has been carefully made highly didactic, and to do so are used all the instruments offered by the multimedia program such as graphics, flow carts, animations. The aim of the part referred to the device is to offer a method of learning all procedures without using any operation manual. In the third part the image reading algorithms (EDR) have been accurately described because of their fundamental role in

forming the CR digital images. To understand this part better, it has been supplemented with a wide survey of images referred to reading errors. Finally, the last part is mainly dedicated to radiologists, for whom the fundamental principles of image enhancement are described,

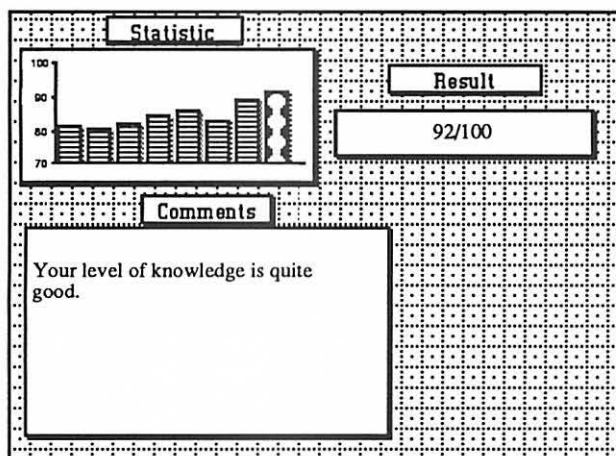


Figure 1: comment card of self-evaluation

while the chapter is accompanied by a series of easy exercises. Each section of the program is equipped with tests to check the learner level of knowledge. The self-assessment [3] is made as follows: the learner answers a series of questions which are automatically evaluated. At the end of the test, according to the answers, a comment card (figure 1) is given to judge the level of knowledge and, if it is necessary, to suggest how

fill up the gaps. On the above mentioned card the comment is integrated by a graphic carrying the user's last ten results and the marks in hundredths. If the knowledge has to be improved some buttons appear and, if they are clicked on, they send back to the section containing the matter to study in detail.

Results and Conclusions

Thanks to this program we have enable all the personnel of the department to use CR correctly. In fact more than 95% of the traditional radiodiagnostic examinations are performed with this technique. Under the operation point of view the radiographers have become more responsible and less material is wasted mainly because exams are not frequently repeat thanks to the capabilities of the image enhancement. Moreover patients are less exposed to radiations (it is necessary only about 50% of the exposure of the conventional screen-film radiography). Under the strictly medical point of view the possibility of postprocessing has made radiological semeiotics more deeply assessable and diagnostics reliability is remarkably increased.

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Dual Energy Subtraction with Single Exposure by CR

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Introduction

By energy subtraction is meant a radiographic technique in which the x-ray dual energy use allows to discriminate among objects that have different atomic numbers. The basis of the single-shot dual-energy subtraction, which is the technique we use, is dependent on the possibility of obtaining an energy separation of the heterocromatic spectrum produced by a x-ray generator. The computed radiography (CR) is technologically suitable for this kind of investigation. Under a diagnostic point of view energy subtraction is used whenever it is necessary to remove the superimposition between different absorption structures.

Materials and Methods

The two different energy images are stored on a system formed by two IPs (Imaging Plate: photostimulable phosphor detector used in CR) between which a 0.5 mm copper (Cu) filter is put. The two IPs and the filter are contained in a radiographic cassette; on the side towards the x-ray source the cassette has two markers that are needed to help automatic superimposition during subtraction processing of the two different energy images. The superimposition of the images, their reading and subtraction process are performed by a CR unit (TCR 3030A, Toshiba, Japan). The images obtained with this technique, one in which there are only soft tissues, and the other only bone structures, are not always satisfactory both because the subtraction is seldom completed and because they are quite noisily.

For the above mentioned reasons the technique has been modified and a prefilter of gadolinium (Gd) has been added at the window of the x-ray source, while the Cu filter between the two IPs has been substituted with a tin (Sn) one. The purpose of the Gd prefilter is to obtain a correct energy separation of the heterocromatic x-ray beam, while the discontinuity of the Gd absorption spectrum (called k-edge point) is correlated to the relative position of the barium k-edge point (barium is the higher Z atom of the active component of the IP screen). As a consequence there will be a kind of window with x-rays of quite monochromatic. The substitution of the Cu filter with a Sn filter, whose k-edge energy is higher, is the consequence of the energy characteristics of the Gd prefiltered beam.

Conclusion

The use of energy subtraction technique opens a wide field of semeiologic acquisitions which cannot be obtained in traditional radiodiagnostics. Undoubtedly image diagnostics will revalue the influence of traditional techniques that are easy to do, of the use of non extremely sophisticated equipment, of the wide range of opportunities offered to radiographers, while the relationship between cost and benefit is quite satisfactory.

However the negative aspects must not be left out: the quality of images is the major problem. The Gd prefilter and Sn filter have improved the quality of images, but they have only partly solved the problems. As a matter of fact one of the most important cause of image quality deterioration is the noise that reduces, and sometimes even abolishes, the perceptibility of the image information. One can intervene both on the prefiltering, for which the present solution is the best, and on the subtraction algorithm which, as it is today conceived, is quite rough and responsible for the noise that could be called "elaboration noise".

A satisfactory solution has not been found yet, and the attempts to get to, follow different trends: a) an analytical way that is the research of valid mathematical functions to correlate the two images to subtract; b) a way that utilises the results of the research into artificial intelligence that are called neural networks; c) the use of fractal techniques.

The results so far obtained in pulmonary pathology are satisfactory and even if they will to have to improve they will justify the routine use of the technique whenever possible.

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Quality Controls by Computed Radiography (CR)

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Introduction

The quality control, in Diagnostic Radiology, has to be intended as a periodical check of the steadiness of x-ray machine standards. It has a very important meaning in medical imaging, considering it both as a control of the steadiness of the x-ray machine performances with high technology and as a control of the reality of the results, in other words of the quality of diagnostic images.

Quality controls are, by definition, "non destructive" controls. In medical imaging there are, nowadays, two possible methods to follow. The first one is the use of dedicated phantoms, densitometrical measurements and measurements of the radiation emitted by ionisation chambers; the other one can use the possibilities offered by the recent CR technologies [1].

This paper is dedicated to the use of CR in the field of quality controls.

Materials and methods

CR unit: TCR 3030A (Toshiba): He-Ne laser reader able to scan with 0.1 mm pitch, with a 10 bit analogic digital converter (ADC). *Photostimulable phosphor detectors, called Imaging Plate (IP) (Fuji):* BaFBr: Eu²⁺ crystals dispersed in a binder and coated on the support, size 35 x 35 cm, able to store the radiant image for a certain period of time. *Processing Workstation TOF 20A (Toshiba):* made up of M68030 microprocessor able to display on a high resolution monitor (2048 lines) and to process the digital images read by the CR unit. *Setting phantoms:* Step aluminium wedge (15 steps), perspex block 10 x 10 x 4 cm, lead cube 5 x 5 x 5 mm. *Controlled devices:* x-ray source, anti-scattered grid, linear tomograph.

The phantom radiant image is stored in the IP as a latent image (electrons trapped in the F-Centers), and then it is read by the Digital Readout System. The image data is transferred as a digital image (characterised by an array of 1770 x 1770 pixels with 1024 grey levels) to the processing workstation. Our attention is addressed to the quality control of the x-ray source (radiation field, exposure parameters), to the anti-scatter grid (absorption efficiency of scatter radiation, both in quality terms and in quantity terms, abnormal movements of the grids) and to the synchronism of the tomographic technique. X-ray source quality controls have been effected using an aluminium step wedge, exposing it to a x-ray beam and varying the exposure

parameters one by one, in order to calculate each parameter (mA, ms and kVp) [2]. The radiation field measurements have been executed exposing the IP directly and then calculating the densitometric profiles. To check the grids we have used a perspex block

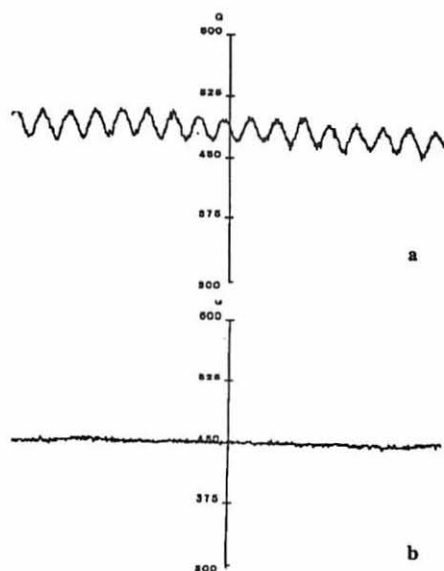


Figure 1: in figure 1a you can notice a sinusoidal trend of the densitometric profile of a moving grid whose movement was altered because of the release of a check pin. In figure 1b you can see the profile of the same moving grid after the repair of the failure.

in order to obtain a great deal of scatter radiation. As far as the quality measurement is concerned the x-ray beam has been narrowly collimated, which has made us quite precisely evaluate the spatial efficiency of the reduction of scatter radiation by means of the grid. As far as the quantity measurement is concerned we have put a beam stop (lead cube size 5 x 5 x 5 mm) into the collimated x-ray beam [3]. Its function is to stop the primary radiation to be able to calculate the scatter radiation only. The characteristics of the tomographic technique have been checked by an IP exposed to the linear tomographic movement without phantoms. Then the obtained image has been analysed by means of densitometric profiles.

Results

The results referred to the three examined devices are separately analysed.

X-ray source: The densitometric profile of the radiation field image has enabled us to evaluate the radiation emission uniformity and to identify the heel effect. The exposure parameters have been measured by histograms from which we were able to verify the linear response both of the circuits and of the exposure timers.

Anti-scattered grid: The densitometric profile has been made use of as an evaluation index of the artefacts due to the use of the grid (figure 1). The histogram, calculated in the area under the beam stop, quantifies the grid efficiency, while the direct evaluation of the perspex phantom proves the grid spatial efficiency.

Tomography: As an example we have analysed the linear tomography, but the same method can be used for all the other tomography conventional techniques. The densitometric profile enables to precisely define the relationship between the tomographic device movement and the length and uniformity of the x-ray source.

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Digitized Film Radiography and Teleradiology versus Plain Film Radiography: Study of Skeletal Fractures

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1.- Introduction

Conversion from conventional radiography systems to digital imaging and transmission of these images has several major advantages. These procedures provide improvement in image processing, storage, retrieval and display. Teleradiology make possible the interpretation of radiographic images from rural areas, subspecialty consulting, back up and its use in emergency departments.

Skeletal radiography accounts for a large fraction of the total number of plain film examinations but there is only limited experience in skeletal applications of these techniques ^{1-3,5}.

We want to assess the diagnostic accuracy of digitized film radiography (DFR) and digital teleradiology (DT) for detecting bone fractures.

2.-Methods and Materials

Case selection.- 290 single radiographs from 124 patients with and 49 without bone fractures were collected over a 3-month period. The patients ranged from 2 years to 83 years in age (mean, 27.9 year). Radiographs chosen represented a wide variety of bone fractures. 34 of them were classified as subtle fractures. Clinical data, additional imaging modalities, follow-up examinations, and the consensus of three non observers (two radiologists and one orthopedic surgeon) were used to confirm the diagnosis.

The Teleradiology System.- The 290 radiographic examinations were laser-digitized at a spot size of 135 μm , a contrast resolution of 12 bits, and a spatial resolution of 2.88 line pairs per millimeter (Dis-1000, Lumysis Inc.). The digitized images were transmitted via standard telephone line between our hospital and "Virgen del Val" hospital, which were located ten kilometers apart. The telephone line has a transmission rate of 19200 bytes of information per second. Data compression techniques were used to improve image transfer rate. Factors of three and six provide transmission times ranged from 45 seconds to 4 minutes and 20 seconds (mean, 2'25").

Both, digitized images and transmitted images were viewed on a 1280x1024x8 bits monitor with image manipulation functions (magnification, brightness-contrast, inverse imaging).

Interpretation.- The conventional radiography, the digitized film radiography and the digital teleradiology images were reviewed by three experienced radiologists (one of them has a special dedication to skeletal radiology). Each radiologist waited twelve weeks between reading original radiographs, digitized images and transmitted images. Clinical information was avoided.

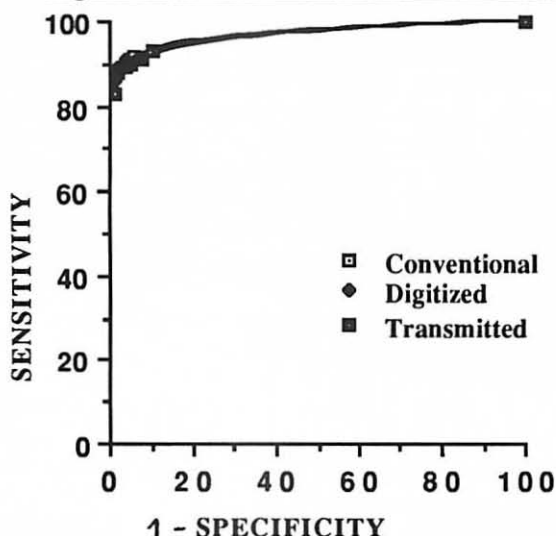
Data Analysis.- Receiver operating characteristic (ROC) analysis was performed. To calculate the statistical significance between the ROC curves, we used a z-scored test of the difference between the areas under the ROC curves.

3.-Results

	Conventional		Digitized		Transmitted	
	W	SEw	W	SEw	W	SEw
Reader 1	96.1	0.019	96.1	0.021	97.2	0.015
Reader 2	94.5	0.019	93.5	0.015	93.8	0.020
Reader 3	94.8	0.019	92.4	0.025	93.0	0.019
Mean	95.1	0.011	95.1	0.013	94.6	0.011

No significant differences were found nor among readers nor between the techniques for detection of bone fracture.

Fig.1.-ROC curves.Bone fracture detection.



4.-Conclusion

DFR and DT could play an important role in the management of patients with bone fractures. General advantages of these techniques are :

- Interpretation of radiographic images from people who reside in health-undeserved rural areas.

- Images are quickly available in the emergency rooms.

- Transmitted images can be used in treatment planning, definitive diagnosis, subspecialty consulting and back up.

- Potential operational improvements are offered by digital radiology.

- Teleradiology unit can be connected to PACS.

Further studies are necessary in order to determinate whether DFR and DT might be applicable for special fracture screening (i.e. subtle fractures⁴, cervical spine fractures⁶)

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Digital Images of Normal Chest: Computed Radiography, Digitized Film Screen and Teleradiology versus Conventional Image

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1 - INTRODUCTION.-

With the advent of computed radiographic system, there is a need to determine the diagnostic quality of digital images as compared to traditional analog film.

Chest radiographs constitute 40% of conventional radiographs in most departments, and require high spatial resolution and contrast sensitivity across a wide dynamic range to the diagnosis of the chest disease.

The screen film chest radiography has a high sensitivity, about of 95% , and is at the moment, despite an increasing availability of more sophisticated cross-sectional imaging techniques , the better technique to chest studies because of its simplicity, effectiveness and wide availability. However , on screen --film chest, the mediastinum is an area of low optical density that is often inadequately visualized.

There are several forms of digital imaging which potential advantages include dose reduction, electronic image transfer and archive, image manipulation, wide dynamic range and high potential contrast resolution. The virtual elimination of exposure errors ought to help improve every day chest imaging.

However there is relatively little experience utilizing digital imaging techniques for conventional radiography.

The purpose of this paper is two-fold. First , we evaluate two types of digital systems: storage phosphor and film -- digitized and we compare both with conventional film screen. Second, we evaluate the chest radiography before and after of its teletansmission.

2 - MATERIAL AND METHODS.-

One hundred patients with normal chest radiography were selected from a population of outpatients. Fifty radiographs were obtained with computed radiography, and other fifty with conventional system. The fifty normal chest radiography obtained with conventional system, were digitized and after teletransmitted by standar telephone line.

The computed radiographs were obtained with a Philips Computer Radiography (P.C.R.) . The cassettes used for chest examinations were of 35x43 cm and the image was evaluated in hard copy of 21.5x17.5 cm with two images : one was simulating a conventional film screen and one was contrast enhanced using unsharp masking. The spatial resolution was 2.5 pl / mm .

To obtained the digitized film a laser film digitizer was used with size matrix : 2048x2048 , spatial resolution : 3584 pixels /line and contrast resolution : 12 bits.

Teletransmission was made with a teleradiology system by standar telephone line , with 5 km between both places.

The digitized and teletransmitted images were displayed on the high resolution monitors.

Four sets of 50 posteroanterior chest radiographs each one, conventional, Computed Radiography (C.R.), digitized and teletransmitted film, were interpreted by three radiologists. A study questionnaire listed fourteen anatomical thoracic structures, located in mediastinum, lung and thoracic wall. Each reader was asked to decide if each structure was present or absent. C.R. and conventional images, were evaluated in hard copy and conventional film respectively. Digitized and transmitted images, were evaluated in video display. The readers were permitted to manipulate any of the video controls (window width, zoom...)

A total of 8.400 observations was made. The data from four sets of images were analized with the Chi-Square analysis, with a confidence level of 95-99 % ($p < 0.05$ - $p < 0.001$)

3 - RESULTS AND DISCUSSION .-

An ideal image receptor for chest radiography should be highly sensitive to radiation (speed) and respond to a wide range of exposures (wide latitude) . Even though conventional screen-film systems provide excellent spatial resolution and sensitivity, the requirement of wide latitude can not be met without sacrifice of contrast. Conventional chest radiography is also limited by scatter , particularly in the mediastinum. Research in digital radiography of the chest has been proceeding on several fronts during the past few years, and there is a good evidence that some limitations of screen-film radiography can be eradicated or at least diminished by digital techniques.

We found considerable improvement, with difference statistically significant, in the visibility of normal anatomical structures in mediastinum, retrocardiac area and ribs, both C.R. and digitized and teletransmitted films.

Results such as these in digitized and teletransmitted film, raise questions regarding the possible contribution to diagnostic accuracy of interactive video manipulation.

Although the transmitted image was of lower quality than digitized image, it was, in general better than conventional image.

In our opinion , all chest images obtained with digital systems, are in general , similars than conventional film, and better than it, for mediastinal structures, retrocardiac area and ribs visualization.

5.-CONCLUSION .-

Digital systems is an alternative approach that provides the optional benefits of digital radiography such as consistent image quality, image processing, and digital archive. However, is of particular importance, the issue of cost and must be considered when evaluating options.

Radiology Computer Management Systems: A British Experience

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1 Introduction

South Tees Acute Hospitals NHS Trust is one of the largest Trusts in the UK. Serving the population of Teesside and East Cleveland on the North-East coast of England it provides a number of Regional and Sub-Regional specialties and prides itself on providing a high quality service at the leading edge of healthcare.

The Division of Radiology has Departments on six hospital sites geographically separated by upto twenty miles. These range from single rooms in the four Community Hospitals to the larger Middlesbrough General and South Cleveland Hospitals, the latter housing state-of-the-art CT and MRI.

164,000 examinations are undertaken annually using the most comprehensive range of imaging equipment in the North Regional Health Authority.

2 The System

2.1 Application Software All of the Departments use the "Radwise" Computer Radiology Management System.

2.2 Hardware The system operates on an IBM RS6000 using RISC 6000 system. The operating system is AIX, an IBM UNIX derivative. The system has 55 terminals/PCs, 7 laser printers and 11 dot matrix printers. This was chosen as it is multitasking, multiuser environment and ideally suited to the needs of the Department.

2.3 Network The system is linked Trustwide on a Case 6000 LAN and DX

WAN network. Within the main sites the link is fibreoptic with a Mercury link between sites.

Radwise is a comprehensive system encompassing several modules including appointments, patient registration, archiving of radiologists' reports, film tracing and adhoc enquiry.

Installation began in July 1992 with all sites being active by March 1993. By April 1994 the first financial year of data was recorded and it is on the experience of this year that this presentation is based.

3 Applications

- 3.1 Contracting The system has been used to monitor activity against contracts. In the reformed NHS where General Practitioners in primary care are encouraged to manage their own budgets it is critical that the activity of individual practices and clinicians is recorded accurately and essential that this data may be quickly retrieved and manipulated. With its user-friendly and extremely flexible adhoc enquiry facility Radwise has provided a powerful tool to enable such detailed monitoring.
- 3.2 Internal Service Agreements Within the Trust the system has been used to help establish agreed levels of service between Radiology and other specialties such as Medicine and Surgery. It now has a major role to play in the monitoring of activity at specialty, sub-specialty and ward and/or consultant levels.
- 3.3 Audit It is proving an invaluable tool for clinical audit. For example, it is used to collect data to measure the effectiveness of radiographers in marking abnormalities on radiographs in the Accident and Emergency Department - the "Red Dot" system.

4 Demographic Data and Radiology Records

On an operational level the system allows access to patient's reports, appointment diaries and demographic information from any terminal in any Department, greatly enhancing the ability of all staff to answer patient related queries.

5 Direct Links to other Systems

Links to the Accident and Emergency Department and Patient Administration System to transfer demographic information provide the dual benefits of increasing speed of data input and avoiding the necessity

for patients to repeat this information.

6 Future Development

6.1 GP Access A modem link facility allows General Practitioners in the community to access the Trusts network. GPs can then gain access to the Radiology system initially to read Radiology reports and view patient appointments.

6.2 Single Site Planning - Centralisation of Services The Trust is currently planning for a single-site hospital to provide unrivalled health care facilities by expanding the South Cleveland site to accommodate that work carried out at MGH and NRI. Radwise is proving an invaluable tool in the task of calculating the size of the Radiology Department in this exciting venture. As momentum increases towards the Single Site, the advantages of the computer system to aid strategic planning are becoming increasingly apparent.

7 Conclusion

Having used the system for over eighteen months we feel it has become indispensable. We are still on a learning curve. The systems' flexibility and our desire for continual development of it as we meet the challenges of the changing healthcare environment, suggest that the learning process is far from complete.

RADIMAM.AD: An Ergonomic Software Package for Archiving and Digital Treatment of Breast X-Rays in High Resolution

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I. INTRODUCTION

Conventional film-based mammography or xeroradiography is, and will probably be for some time, the only imaging technique capable of detecting clinically occult breast cancer, (3), etc. Due to the lack of the human eye to obtain all the information presents in a X-ray film, the low contrast of the mammographic image and the fact that an improvement on the quality of the image would correspond with improvements in diagnostic and detection of breast cancer, two specific systems for archiving and digital treatment of breast X-rays have been implemented. These kinds of systems have more advantages over conventional film radiography in image archiving, transmission, processing and display, (1), (2), etc. There are some disadvantages for these systems. For instance, digital X-ray systems require complicated hardware. Furthermore, for the radiologist, these systems are unfamiliar and more complex. To overcome this, a software package has been developed to be as ergonomic as possible, making it easy to use after a short period of learning assuming no prior knowledge of computing.

II. HARDWARE

The package has been carried out on two PC-based general purpose digital image processors, to which adequate peripherals have been added to simplify X-ray handling. The spatial resolution for the first system (Microm-Kontron IMCO_10) is 512x512 pixels with 8 bits of depth, which is found satisfactory for improve many radiological signs. The second system (Microm-Kontron IMCO_500) has a spatial resolution of 1024x1024 pixels with 8 bits of depth, which is found very satisfactory if the X-ray input devices are of adequate precision, but it is possible to upgrade to 2048x2048 pixels of 8 bits or more.

III. DESCRIPTION OF THE SOFTWARE PACKAGE

On the control monitor several screens with windows and pull-down menus with different options have been developed (fig.1). There are three basic operating modules with submodules. They are the Input/Output module, which includes suboptions with capture/recovery and digital output/archiving (these including independent screens for patients data); Radiological Signs (this block contains mammographic processing techniques, both classical and of very recent conception

(4), whose aim is to enhance the information in the mammogram); and Utilities (under this heading several utilities fall such as pseudocolors, labelling, measurements, etc).

Furthermore, in the lower part of the screen (fig.1), there are three basic functions, zoom, false-color and inversion, which appear on the right hand side. In the left hand side is where each of ten mammograms, which can be displayed on the TV monitor, are selected.

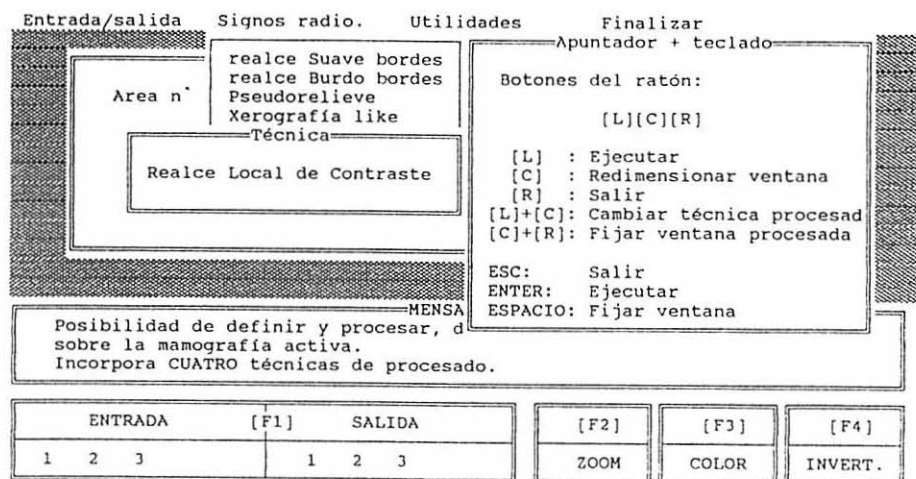


Fig.1.- A Window of the RADIMAMAD

The area between the upper and lower parts of the screen has been used to give information about the use of the option selected as well as the names of the patients corresponding to the five mammograms selected. In this area the different windows of the options of the upper menu are superimposed.

All the information required to use the system is provided at the appropriate time. Also, a mouse is possible to use to simplify its operation for the radiologist. In this way the doctor is there to diagnose and would not need to spend lots of his/her time consulting instruction manuals.

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Digital Imaging of the Breast

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Purpose: A new CCD (Charge Couple Device) camera has been used to digitize breast images for both stereotactic biopsy and also diagnostic workup of microcalcifications and breast masses. The CCD camera is based on 1024 x 1024 pixel format full frame, front illuminated and directly coupled to an x-ray intensifying screen via a 2-inch fiber optic reducer. The CCD is cooled to -10°C and is digitized in slow scan, double sampling mode at 500k pixels per second with 12 bit contrast resolution. X-ray images acquired with the system are processed and displayed on a high resolution monitor within 20 seconds after x-ray exposure.

Materials, Methods, Procedures: 100 women who underwent additional workup for mammographic abnormalities were also worked up with (DSMM) Digital Spot Magnification Mammography. A panel of three mammographers interpreted the results. Using the digital exams, would you interpret microcalcifications and soft tissue masses as benign, malignant or indeterminate. If indeterminate, would you observe (6 months) or biopsy the lesions. Pathology correlation is compared with these results.

Results: DSMM (Digital Spot Magnification Mammography) - the advantages of this technique are fast, real-time filmless imaging with better detectability of low contrast lesions and microcalcifications. The patient dose is decreased. Examples of breast phantom as well as breast pathology will be presented using the DSMM technique.

Conclusion: DSMM shortens stereotactic biopsy time by 50% and also may have a role in the diagnostic workup of breast masses and microcalcifications.

Experiences in Use of a Departmental Information System (Pacs/Ris) in Radiology, Assistance & Education Management

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INTRODUCTION

The worst problems that plague Italian diagnostic imaging departments, even those with a well-organized storage system, consist on troublesome loss of time for retrieval of past radiograms and sometimes their loss¹. The great quantity of paperwork and the need for fast retrieval of the same image from different places have brought the need for computer-based Picture Archival and Communication Systems (PACS)²⁻³. "Text-based" patient care (as patient reception and record keeping, examination reporting, typing and checking) is another source of problem⁴. LineaFILE, created by Sanitaria Scaligera SpA (Verona-Italy) and developed with the help of Radiological Department of "Tor Vergata" University (Rome-Italy), is an information system conceived to join a Radiological Information System with those of a departmental PACS. Its installation in our department also achieved the goal to reunite the two branches of Imaging Diagnostics, located in two separate buildings, into a single Information Network.

ADVANTAGES

Installation of the LineaFILE PACS/RIS resulted in overall productivity enhancement throughout all the structure:

A) GENERAL MANAGEMENT

- Computer-assisted patient reception and automatic examination booking.
- Daily workload planning, divided by section
- Fast and easy reporting (free text, decision-tree and voice-sampling)

B) DATA ARCHIVAL

- Alphanumeric Data - Patient folder, Examination folder, report
- Digital storage of clinical data and medical images (radiograms and digitized film)

C) INTERCOMMUNICATION

- Inter - LAN and remote text/voice mail
- Remote transmission of medical images (teleconference)
- Teleconsulting

D) RESEARCH & EDUCATION

- Patient Data/Examination Data search by keyword
- Statistical studies (no time limit on alphanumeric data; 2-year time limit for images)

second; however, the practical transfer rate is much lower, about 3 Mb/s - sufficient anyway for our needs, since a typical image gets transferred along the net in little more than half a second. Installation of a fiber-optic backbone in the near future is expected to close the gap between teorical and practical transfer rate. Installation of a half-mile-long, high-speed, low attenuation trunk line connected to signal amplifiers and reconditioners allowed us to reunite our two departmens under a single net, extending well over the specification limits for EtherNet - total network extension is now little more than two kilometers - about a mile and a half. Data transmitted on the network are information packages whose alphanumeric part gets stored on the 2 Gb disk array, while image data is stored on the HP Jukeboxes. On-line image capacity is about 320.000 images, or about two years' worth of images. The system, however, keeps track of the physical volume on which each image is stored, asking for off-line volumes to be put online if requested. Search time is under a second, for a database which, at the time of this writing, included more than 25.000 patient records and 40.000 examination records.

Actual data storage is expected to be enough to keep online ten years' worth of patient data. The entire Local Area Network already has remote-link capability, and will allow data to be exchanged through analog modems or via ISDN gateway.

Slides production for educational purposes has been significantly speeded up by connecting a Polaroid CI-5000S Film Recorder to one of the image consulting nodes, enabling this node to produce high-quality true-color slides with 4096x4096 resolution, getting images and patient data directly from the information network.

FUTURE UPGRADES

New perspective are: A) Remote Teleconferencing; b) Built-In Speech Recognition; c) Operating Room Connection; d) Hospital Information System.

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- Production of 35mm dia film
- Separate educational databases for keeping data about the most interesting clinical cases

Such a versatile and sophisticated system allows all activities in our departments: assistential, administrative and research; cautions have been taken to avoid the possibility that a system breakdown could stop work in a department until a specialized technician put the system back on-line. However in our two years experience the system didn't develop unsoluble problems for our personnel thank to the possibility to update system management software and solve problems remotely, from computer to computer, reducing machine down times and avoiding the need for most technical assistance calls. The main obstacle we met was our personnel inadequate computer competence, this caused as a large percentage of problems during initial system start-up. However, we tried to overcome this difficulties by instructing personnel step by step, starting with their specific competencies and adding general computer technology tips, until reaching full working autonomy⁵. The most useful single feature of the system is without doubt the automated reporting system, i.e. the option of determinining pathologies using a preset but modifiable decision tree. Linking preset - but still modifiable - phraseology to each single pathology reduces reporting time to near-zero while labelling univocally each pathology, allowing fast and complete statistical searches. Report text is produced during pathology definition using a few clicks of the mouse, so the typists' task becomes that of simply completing and formatting the text. Images may also be marked during examination, for fast retrieval of relevant cases.

SYSTEM DESCRIPTION

The system we are experimenting includes, as of today :

- 9 Image Acquisition Nodes, connected to CT, DSA, ultrasound and Color-Doppler for acquiring image data directly from the imaging modalities;
- 2 Film Scanning Nodes, connected to 4096x4096, 12-bit X-Ray film scanners, for the purpose of digitizing standard x-ray film;
- 4 Reporting nodes, for image reporting;
- 3 Consulting Nodes, for image display, study, and processing;
- 2 stations for alpha-numeric data input and exam booking & scheduling;
- 2 stations for 35mm hard-copy to product slides.

A new connection, by ISDN link, with a remote station located in Department of Radiology of "Fatebenefratelli" - Isola Tiberina Hospital. Radiologist of both hospitals can be consulted easily and quickly by trasmission of images between two locations⁶. Beside these, the network includes a direct connection to the Laser Imager, three shared printers (laser and ink-jet) and two servers, dedicated respectively to network management, with a 2-Gigabytes (Gb) RAID disk and backup / mirroring software and hardware, and to the management of the Optical Library , where all images get stored on twin HP1718 Magneto-optical Jukeboxes, for a total capacity of 20 Gb. All the stations are connected thru an Ethernet backbone, using EtherTalk (© Apple Computers, Inc) software protocols. This configuration allows for a teorical transfer rate of 10 Megabits (Mb) per

Subtraction of Pre- and Post-Gadolinium Enhanced MR Images in the Evaluation of Osteomyelitis

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Differentiating frank osteomyelitis from overlying cellulitis can be difficult. Various imaging techniques have been proposed, the most promising being indium-labeled white blood cell scintigraphy and magnetic resonance imaging (MRI). Gadolinium-enhanced MRI has been proposed as a sensitive method for the detection of osteomyelitis (1). Combining this with fat-suppression techniques has enhanced the visibility of lesions (2). Questions still arise, however, when making side-by-side readings of pre- and post-gadolinium-enhanced images. Subtleties of marrow invasion by infection may be difficult to distinguish from overlying soft tissue edema.

Pre- and post-contrast infection subtraction studies have been proposed as a means of making more accurate assessment of tumor invasion in the bone (3). We independently made the same supposition regarding the value of subtraction in aiding the visualization of infection in bone. More recently, a color-addition method for creating a color map of contrast enhancement on MR images was published (4). In order to compare the value of both subtraction and color-addition in the diagnosis of osteomyelitis, we set up the following experiment:

Cases of suspected osteomyelitis were imaged on a 1.5 Tesla MR scanner. Fat suppressed T1-weighted spin-echo images were obtained before and after the administration of gadolinium-DTPA. Eighty representative images from eight patients were transferred to an independent workstation where digital subtraction and color-addition were

performed using custom software. Two radiologists experienced in interpreting musculoskeletal MR images were asked to evaluate the pre- and post-contrast images in a side-by-side fashion at the workstation. Using a five level scoring system (definitely no enhancement, probably no enhancement, indeterminate, probable enhancement, definite enhancement), each radiologist evaluated pre- and post-contrast T1-weighted fat saturated pairs of images for enhancement of soft tissues and bone marrow. The evaluations were then repeated using only the subtracted images and, finally, the color-addition images.

As compared to side-by-side evaluation of these 80 comparison slices, subtraction increased diagnostic confidence for at least one of the observers of soft tissue enhancement in 25 slices and of bone marrow enhancement in 23 slices. For the color-addition method, observer confidence was increased in 28 and 21 slices in the evaluation of soft tissue enhancement and bone marrow enhancement, respectively.

We conclude that, although subtraction or color-addition processing improved observer confidence in some cases, in most cases there was no improvement. Factors that hindered the success of the processing techniques included patient motion, inhomogeneous and inconsistent fat-suppression, and technologist-related misregistration of pre- and post-contrast slices.

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Computer Based Monitoring System for Monitoring Physics Related Measurements in a Large Diagnostic Facility

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Introduction

The utilization of modern computing and networking capabilities to monitor the performance of x-ray systems on a regular basis is beneficial in terms of good patient care. In a large diagnostic facility such as The Johns Hopkins Hospital where there are more than 100 of these units, follow-up on each of these tube on a periodic basis is an enormous task. A computer system is currently being developed, to provide easy access to physics related measurements. The system will have various users such as technologists, service engineers medical physicists, area supervisors and managers. Whenever an x-ray machine undergoes service or preventive maintenance, measurements for testing exposure reproducibility, kVp calibration, half-value layer, entrance skin exposure and other related data will be entered into the system. These data can then be easily accessed through the network by authorized users.

System Design

The system was designed to track any type of physics related measurement performed on the x-ray equipment. In addition to annual inspections performed for complying with the state and federal regulations, periodic measurements are done after preventive maintenance and after service performed on x-ray equipment. The system software will enhance the accessibility to the recorded data.

The physical organization of the radiology department at The Johns Hopkins Hospital is very complex. The imaging equipment is distributed throughout the inpatient and outpatient facilities of the hospital in several sub-divisions such as general radiology, neuroradiology, pediatric radiology, and cardiac catheterization laboratories. Currently each of the locations is linked through the radiology network. The equipment service software is on the same network. After each preventive maintenance or service activity, a Quality Assurance technologist from the Physics and Engineering Services group performs QA tests and reports the data at terminals on the network. This enables the medical physicist, the area supervisor and the manager to monitor the performance of the equipment.

Hardware and Software

The hardware consists of NetFrame 400 super server running Novell 3.11 (Novell Network System, Novell Inc., Utah). The network is installed and supporting all of our equipment service activities and applications. The network stations have varying components ranging from IBM PC model 5150's (the originals) through 66 MHz 80486 (Gateway 2000 4DX2-66V) and Pentium (Gateway P5-60) systems. The software for the database was developed in Clipper, versions Summer 87 to 5.02B, using the program editor (PE.EXE) which is part of WordPerfect Office for DOS. The network library is NetLib from Pinnacle Publishing, Inc. and the communications library is CommTools, also from Pinnacle Publishing, Inc.

Conclusions

The basic design of the software allows tracking of measurements done on all types of x-ray equipment. This software is complementary to the existing equipment service activity reporting software running on the same network. The utilization of the system is in a relatively early stage. Additional applications of the software are being investigated which will be reported at future meetings.

National Teleradiology System

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Health care system and Teleradiology

The Icelandic health care system is based upon primary health care centers and general family practitioners. These institutions are linked to hospitals of various levels but four hospitals and one private institution provide radiology service. The University Hospital and the Directorate General of Health (part of Ministry of Health) have developed a plan to establish a Teleradiology service to the remote hospitals, which have no permanent radiological service, and also to some primary health care centers. At least 5 institutions will be connected this year and another 10 next year. The purpose is to provide specialist service to clinicians in remote health care institutions using one coherent country-wide network.

These institutions are chosen according to extent of their service and examinations and geographical location. The University Hospital and one remote hospital (in Akureyri) will act as receivers and in fact any institution can be connected for this service.

This plan is a result of a Teleradiology project that has been in operation for the last two years.

Communication Technology

Public communication system will be used and communication media that are suitable for each location according to speed and cost. Mainly it will be chosen between two methods according to data flow and load :

1. Network using TCP/IP protocol providing Ethernet connection between institutions with present transfer speed of 64 kb/s to 2 Mb/s.
 2. Modem connection, leased lines and dial-up connection. Speed up to 28.8 kb/s.
- These connections will be transparent to the user.

Other types of methods like ISDN are prepared for 1995.

Image Quality

Most of the institutions can be expected to perform all general X-ray examinations and therefore film scanning equipment has to be prepared for that. It has been found adequate to digitize film with 2000 X 2000 X 12 bits^{1,2}. However bearing in mind that laser film hard-copier go to 4000 X 5000 X 12 bits, then it may be expected that film digitizers for X-ray films may need to have resolution in the extent of 4000

pixels and 12 bits grey scale. This applies especially if digital Teleradiology is going to be utilised both as a diagnostic and as a consulting tool and totally replacing the film³.

It is our conclusion that no compromise can be made in terms of image quality in the film digitization. Since film scanners commercially available were found to be insufficient even for small hospitals when considering the price versus image quality, it was decided to design a film scanner with high image quality and a more affordable price. This has been a joint project with the University of Iceland and a local company, both which have considerable experience with CCD cameras. This is done to provide better service to the hospitals and being able to respond better to changing technology. In the film scanner under development, image quality can go up to 5000 X 6000 X 12 bits, but lower resolution can be chosen mainly to compromise data amount to existing computer and communication technology. Scan time will be in the medium range, < 1 min.

To ensure high data throughput on the network, various image compression methods are being utilized.

Standard data format

Available data formats are used according to standards in medical imaging, like DICOM and Papyrus, and common in computer graphics, like TIFF. This to ensure that institutions can use different viewing software and also that images can be sent or received from elsewhere for further consultations.

Telemedicine service

Each sending hospital will have simple software for image viewing and transfer (in-house designed). The receiving hospital can use divers software (like OSIRIS) provided that it can accept standard image format.

The receiving station in the University Hospital is connected to the hospital network so images can be sent to clinicians, after radiologist review, providing better service to remote hospitals by direct contact with the specialist.

This National Teleradiology network provides arrangement for other forms of Telemedicine service which are under development and is being formulated as a National Healthnet.

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Unsharp Masking Filters of Breast Radiographs in the Frequency Domain

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I- INTRODUCTION

Unsharp masking technique, widely used for image edges enhancement, consists in simulating a high-pass filter by subtracting to the original image a smoothed version. It is a standard feature of many modern digital radiography apparatuses, and in this context is particularly useful for clinical interpretation of breast radiographs. Although recent improvements have reduced the noise problem inherent in the enhancement of high frequencies, and allow selective edge enhancement and greater contrast (1), the mask parameters have in all cases been determined by trial and error using subjective criteria and/or subsequent R.O.C. validation. In this communication we report steps towards the objective calculation of optimal parameters ensuring maximum edge enhancement and dynamic range while retaining low-frequency image structure and minimizing noise.

II. THE GENERALIZED UNSHARP MASKING FILTER

The standard unsharp masking filter effects the transformation

$$I_{OUT}(x, z) = K_0 I_i(x, z) - K_1 I_{s1}(x, z) \quad [1]$$

where I_i and I_{OUT} are respectively the input and output images, I_{s1} is the smoothed image and k_0 and k_1 are real constants.

This filter can be generalized to involve a finite number of smoothing images:

$$I_{OUT}(x, z) = K_0 I_i(x, z) - \sum_{i=1}^N K_i I_{si}(x, z) \quad [2]$$

In this paper, as in previous work(1), we limit our attention to the case $N=2$. The smoothed images are obtained by convolution of the input image with the masking function $h_i(p, q)$, where h_i is a simple two-dimensional square pulse masks of the form

$$h_i(p, q) = \begin{cases} 1 & |p| < \frac{L_i}{2} \text{ y } |q| < \frac{L_i}{2} \\ 0 & \text{otherwise} \end{cases} \quad [3]$$

$i=1,2$ and L_i is a real constant.

III.- CALCULUS OF THE MODULATION TRANSFER FUNCTION

To calculate the m.t.f. of the filter we translate to the fourier domain

$$I_{OUT}(x, z) = I_i(x, z) \star h(x, z) \quad [4]$$

where

$$h(x, z) = k_0 \delta(p-x, q-z) - k_1 h_1(p-x, q-z) - k_2 h_2(p-x, q-z) \quad [5]$$

and results

$$|H(u, v)| = k_0 - 4k_1 \frac{\sin \frac{L_1}{2} u}{u} \frac{\sin \frac{L_1}{2} v}{v} - 4k_2 \frac{\sin \frac{L_2}{2} u}{u} \frac{\sin \frac{L_2}{2} v}{v} \quad [6]$$

IV.- CONDITIONS ON THE PARAMETERS K_i AND L_i

The parameter k_0 is fixed equal to unity by imposing the condition that, in order to avoid loss of dynamic range and distortion, the gain of the filter should be unity at frequencies above cut-off. The values of the L_i must be found empirically (though not necessarily by trial and error), because they depend on the desired cut-off frequencies, i.e. on whether the edges to be enhanced are coarse or fine, which ones may be less than the maximum spacial frequency of the original image, the breast mammography in our case; specifically, since the cut-offs for this purpose be taken as the first zeros of the sinc functions in equation[6], their relationship with the L_i is given by

$$\frac{2n\pi}{L_i} \quad i=1, 2 \quad n \in I \quad [7]$$

Once the L_i have been decided on, the values of the k_i are constrained by imposing the condition that, since the unsharp masking filter is a form of high-pass filter, the gain of the filter should be zero for a constant signal:

$$H(0, 0) = 0 = k_0 - \sum_{i=1}^{i=N} k_i L_i^2 \quad [8]$$

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Nordic Teleradiology and Telemedicine Consultation Network

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Introduction

The Nordic countries are sparsely populated, yet they have good governmental and communal health care systems. They have developed modern telecommunication networks both on national and international levels.

The academic hospitals in the Nordic countries have established comprehensive knowledge and experience in the various fields of medicine. Because level and range of expertise can vary between institutions, situation comes up where specialists in one institution want to discuss and get consultation on a clinical case or a single examination. These institutions can also consult and give necessary specialist service to smaller and remote health care institutions.

There are over 18 major University hospitals in the 5 Nordic countries and the number of academic institutions can be estimated to be double that figure. By connecting all those institution together by communication network, a comprehensive service can be established with better exchange of clinical information. Such an arrangement may be called Telemedicine service.

Model for consultation network

Considerable experience has been gained in Teleradiology, one form of Telemedicine service, in the Nordic countries. The need for effective data transmission systems in modern medicine calls for easy access to open systems. The possibility and the feasibility of using a world widespread computer network system, called Internet, for Telemedicine purposes between the Nordic countries is being investigated. The Nordic part of Internet is called NORDUnet (NORDic University Network).. The Nordic consultation network can provide a general system in which all major institutions can be connected and thereby providing quick and more cost effective service which will strengthen the expertise on all levels, especially in the smaller institutions.

A Teleradiology consultation system has been tested between the University Hospital of Iceland and Oulu University Central Hospital in Oulu, Finland, using Internet. The departments of radiology have connected their computer networks to Internet and are testing automated image transfer to and from the Internet gateway. These institutions with the University of Tromsø, Norway, have in a recent study sent a number of radiological cases to test the feasibility of this service.

On using open network

Because this network is very open, personal information as text has to be encrypted but not the images. This applies both to requests and reports.

Hospital networks need to be protected from intruders. User access from NORDUnet to hospital network will be restricted by use of secure gateways. Further limitation of access is to have Teleradiology workstations not connected to hospital network and transfer data instead on a high capacity medium, like optical disks.

Because public telecommunication system is used, the transfer speed can vary. Presently most links are running at 64 kb/s or higher. But low speed links also exist. Improvement will gradually remove these limitations. Our experience suggests that 64 kb/s can be sufficient for batch mode transmission.

Functional considerations

Openness is a large issue and the use of general or standardized file format for medical images is important. The use of the DICOM standard and the PYPYRUS file format (University Hospital in Geneva) is under testing. ASCII is used for text files. To ensure high data throughput, data compression is necessary. In our project both lossless and lossy methods have been tested. We have used the standard JPEG compression with compression rate of 10:1 both in tomograms (MRI and CT) and also conventional X-rays without visible loss in image quality.

Conclusion

The need for effective data transmission systems in modern medicine calls for easy access to open systems. The NORDUnet (and its parent, Internet) can provide easy and cost effective transmission between high-speed local or proprietary networks. The use of NORDUnet for Teleradiological purposes is being further investigated so permanent service can be established.

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Demonstrations

Anatomical Modeling from CT Scan Data

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Overview

There are four basic steps in generating a physical model from CT data. The first step is the CT scan. There are various protocols required to facilitate the best data acquisition for the model. The second step is delineating a subset of the CT data which will describe the model itself. This step is referred to as segmentation of the data. The data is then translated into a rapid prototyping format and fabricated.

Data Acquisition

The data for the model can come from a wide variety of CT scanners. For the best results strict protocols must be followed to ensure the best possible data to work with. A key procedure in these protocols is the use of a plastic rod attached to the patient. This rod is included in the scan to ensure that the patient has not moved during the exam and also ensures proper calibration.

Segmentation

Some traditional approaches to anatomical modeling involve digitally tracing contours off the screen rather than use the actual CT values. These traced contours are really an interpretation of the CT data just as medical illustrations are. This phase is much less subjective when powerful segmentation tools are used to delineate the data. With segmentation tools such as thresholding and standard deviations, a technician identifies the three dimensional region of data to describe the model. This is done slice by slice through the whole CT exam after which the slices are reconstructed into a three dimensional object. The reconstruction step also interpolates between the slices. This interpolation "fills in the gaps" between the slices which will ultimately produce a smoother model. Otherwise, the model would have a noticeable "stair step" effect which is not representative of the true anatomy it is describing. Past alternatives have involved smoothing the models by hand. Segmentation is one of the most important steps because this is where the data which defines the model.

Data Translation

For the model to be fabricated, the machine which processes the model must be able to interpret the 3D CT data. What we are translating the data from is referred to as raster data. Raster data can represent a picture such as a photograph or in this

case a CT scan. This raster data is translated to point and vector data. Point and vector data has been used to represent engineering prototypes using Computer Aided Design (CAD) from simple parts to complex assemblies. This translation is the last step to bring the technology of CT scans to the power of rapid prototyping which, to this point has only been available to the engineering community. This translation process has been entirely automated.

Rapid Prototyping Techniques

Since the inception of computer milling, the Computer Aided Manufacturing (CAM) industry has come out with many techniques to produce models. These techniques are referred to as Rapid Prototyping. Various rapid prototyping technologies evolved to facilitate rapid, accurate reproductions of CAD drawings into a physical 3 dimensional model usually made of a plastic. Over the last three years, we have researched many of the rapid prototyping technologies to find one best suited for reproducing human anatomy which greatly differs from the typical CAD drawing. We believe this technology to be that of Solid Ground Forming (SGF). The SGF process has the greatest accuracy especially when representing internal features such as the foramina canals in bone.

The Solid Ground Forming Process

This process manufactures the models in layers. Each slice is prepared in a series of steps. First a layer of photo-polymer is spread on the base of the table on which the model is grown. The photo-polymer starts out in a liquid state and is hardened or cured by a specific spectrum of light.

Once the polymer is spread on the model building table a photographic mask is produced. This mask is made on a pane of glass with the underside of the glass coated with mylar. The mylar allows the plate to be electrostatically charged. This charge is applied to the glass plate in a similar manner that a laser printer applies toner. Once the plate has been charged, a toner is applied to the glass and sticks only to the charged portion of the surface. Now the photographic mask has been produced.

This glass plate is now moved over the base of the modeling table where the photo-polymer has been applied. When the plate is in position an intense ultra-violet light is cast down through the mask onto the photo-polymer which instantly hardens.

The light is turned off and the table now moves out from under the mask to a vacuum nozzle which removes the uncured liquid polymer that was shielded by the mask. At this point a thin layer of hardened polymer remains showing a "positive" of the first slice of the model.

The modeling table is now moved to a liquid wax applicator which backfills the whole region filling in the areas where the uncured polymer once was. The wax is then hardened with a cooling plate. Once cooled, the wax and cured polymer are milled down approximately two thousandths of an inch which levels out the whole layer.

The table is lowered slightly and the whole process is repeated, beginning with the application of the liquid photo-polymer. The wax serves as a supporting structure until the model is completed, after which the wax is washed away with warm water.

An Interactive Computer Program on the Principles of Nuclear Radiation to Facilitate Student Learning and Self-Evaluation

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This interactive program's two-fold purpose is to teach the basic principles of radiation and the interactions of radiation with matter. The first learning module concentrates on the fundamental principles of radiation physics, using the concept of energy conservation as the conceptual link. Objectives of the first learning module include developing a working knowledge of radiation, and atomic and nuclear composition in terms of energy, stability, and decay. Additional objectives include utilizing the units of activity and the parameters of the exponential decay relationship.

Learning module two moves the student beyond the generalized decay processes and into the specific modes of decay and the interactions of these emissions with matter, while maintaining the underlying concept of energy conservation. Objectives of the second learning module include describing and predicting the modes of radioactive decay, decay schemes, and emission energies utilizing nuclear terminology. Further objectives include describing the effects of the interaction of particulate and photon radiation with matter and using the parameters of the exponential attenuation relationship in a health-physics oriented laboratory simulation. Also the basic principles of radioisotope generators, cyclotrons, and particle accelerators are discussed and treated as graphically based simulations.

Each of the interactive learning modules in this program utilize a pretest, stated learning objectives, an interactive informational component, hands-on laboratory simulations, a summation, and a post-test. Test questions focus on the student's factual recall, interpretive analyses, and problem solving abilities.

The authoring system for the Macintosh known as Authoware (TM) is used to allow for a sophisticated interactive testing of students. The exhibit is presented on a Macintosh Centris (TM) computer. The ability of the computer simulation to bring abstract concepts to a concrete level greatly facilitates learning. Further advantages of computer based instruction are in its suitability for individualized study, its interactive nature allowing for immediate feedback, and its ability to administratively document test results.

Total Quality Management with Portable Computer Databases

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PURPOSE: The Joint Committee for the Accreditation of Hospitals and Care Organizations (JCAHO) requires continuous monitoring of patient care in order to detect deficiencies and improve quality. Certainly within a Radiology Department this involves documenting results and complications of invasive procedures, noting the agreements and disagreements on double readings of studies or on comparisons of imaging study interpretations with pathologic and clinical diagnoses, as well as recording the results of research protocols which may affect patient care. Tracking and recording these data can be time consuming. Recently, advances in semiconductor design have resulted in the development of powerful lightweight pocket-sized computers which could allow a radiologist to enter information at the "point-of-care" thus simplifying data collection [1-3]. This study was undertaken to determine if simple databases on a palmtop PC or personal digital assistant (PDA) could successfully monitor various quality assurance and quality improvement activities within a section of an academic radiology practice.

METHODS: A Hewlett-Packard 95LXTM with a proprietary database program and Lotus 123 TM (v 2.2) was used to collect and sort patient data within the Neuroradiology section for 18 months; an Apple Newton Message PadTM was used for 3 months. Pertinent data on patients undergoing invasive procedures, presented in conferences, or enrolled in research protocols were tracked. Double readings of imaging procedures, and pathologic correlations with imaging interpretations were similarly followed. The data from the procedures were correlated with patient billing data to determine if any records were lost or not recorded.

RESULTS: The portable computerized database permitted easy "point of care" data entry. Cross-checking with patient billing for procedures performed revealed no loss of patient data (216 total cases). All data were readily retrievable and downloaded to desk top PC's for permanent storage, statistical analysis, and preparation of reports for departmental review.

CONCLUSION: Pocket-sized computers offer an easy and accurate method for recording and monitoring total quality assurance and improvement activities within a radiology department[2]. With further technical advancements, these computers should offer means to make billing and scheduling more efficient as well.

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Computer Segmentation of Complex 3D Structures for Holographic Visualization

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Introduction

Three-dimensional visualization of complicated structures can aid in medical diagnosis, teaching and explanations to patients. Magnetic resonance imaging (MRI) allows non-invasive imaging of complicated structures. However, simple, intuitive presentation of MR data can be difficult due to the vast amount of information that is gained from a comprehensive session using fast imaging methods such as turboFLASH or echo-planar imaging. (Similar difficulties can arise with other fast imaging methods.) We have selected the human coronary arteries as examples of complicated structures with fine detail that are well-presented as (3D) holograms.

Methods

Stacks of contiguous thin cross-sectional slices covering the entire hearts of normal volunteers were acquired on a Siemens 1.5 Tesla MRI scanner (Siemens Medical Systems, Erlangen, Germany) using a segmented turboFLASH sequence. Imaging parameters were: TR=130ms, TE=7ms, THK=3mm, FOV=300mm, Matrix=130×256. Each individual image was obtained with ECG-trigger on a single breath-hold, over 13 heartbeats. No contrast agents were employed.

Images were transferred from the MRI scanner to a SPARC workstation (Sun Microsystems, Mountain View, CA) for processing by CUBE™ software (Unified Medical Systems, Brookline, MA) which identified and removed bloodpools from each image. Such bloodpools tend to obscure arteries in typical maximum intensity projections (MIPs). Segmentation was performed automatically, requiring only two mouse-button clicks for user input. The first click defined the statistically optimal border between "object" and background, the second selected the object. (Segmentation can be propagated throughout the stack for convenience, while allowing the user to make frame-by-frame updates if desired. Additionally, images can be reregistered in-stack in the event of patient motion between acquisitions.) This processing resulted in visualization of the 3D coronary tree, including distal branches of the right and left systems not previously seen by

noninvasive methods. Stacks consisted of approximately 50 images, with the exact number depending on subject size.

Segmented image stacks were converted to volumetric holograms by the Voxel Corporation (Laguna Hills, CA). These films provide full three-dimensional depth cues when viewed on a Voxel holographic lightbox. In lieu of holographic presentation, not possible here, figure 1 is an example of how computer processing is applied to reveal right coronary artery (RCA) from a series of six views in which RCA is partially obscured.

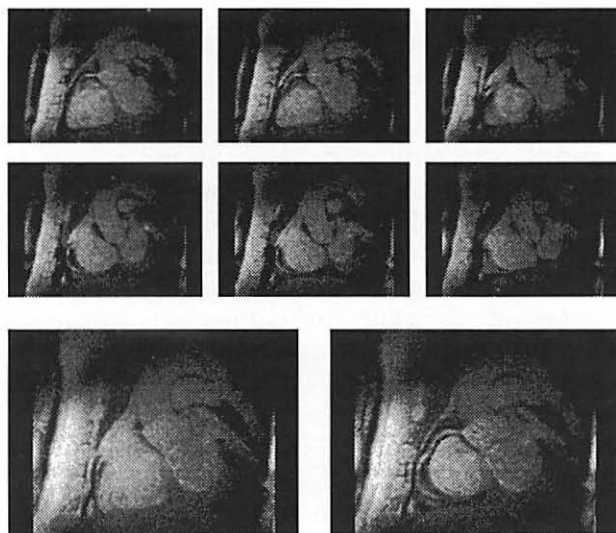


Figure 1. Original frames are shown in the top two rows, their MIP is shown bottom left, where much of the RCA is obscured by overlying bloodpool. Bottom right is selective MIP showing significantly greater portion of RCA after removal of obscuring bloodpools by computer processing.

Discussion

Imaging modalities such as MRI and CT can produce overwhelming amounts of output. Presenting information from such a wealth of data in a simple and clear way is challenging. Voxel volumetric holograms allow natural viewing of complex structures in apparent 3D. In the example application of visualizing human coronary arteries, MRI by itself allows views not obtainable by x-ray angiography. The addition of automated segmentation and holographic display allows post-imaging viewing of the coronaries from multiple orientations in addition to that from which the MRIs were originally obtained. Physicians viewing the holograms have reported that relative to a collection of ordinary "flat" films, holographic display substantially decreases the amount of effort required to visualize complex three-dimensional structures, helping them make more comprehensive diagnoses.

Development of an Image Display and Analysis Workstation in a Visual Basic Programming Environment

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A versatile medical image display program was developed in the Visual Basic¹ programming environment. Visual Basic is an easy to use object-oriented programming environment for Windows¹ programming environment. As in other object-oriented programming environments, a variety of controls are provided. Interactions of a pointing device within the area of the screen occupied by a control activate program subroutines associated that control. In addition, a wide variety of specialized controls and tools are available from third party vendors. One of these, VisionTools², was used in the development of this application.

The display software includes the following features:

- (1) Add-on modules for filtering of imported image formats.
- (2) Static display of 1 to 30 sequential images.
- (3) Paired displays of 2 to 6 sequential or tomographic images.
- (3) Single and dual simultaneous cine loop viewing.
- (4) Pop-up magnification and scrolling of images.
- (5) Individual scaling of single images or simultaneous scaling of all displayed images.
- (6) Display of images in one or more color palettes.
- (7) Extraction of quantitative image data from user-defined regions of interest (ROI), including ratios normalized for ROI area.

Examples of applications of the program to nuclear medicine and MR data will be demonstrated. Acceptable performance is possible using a 486SX25 processor.

The availability of an easy to use and easy to program graphical-user-interface allows the programmer of moderate sophistication to produce general purpose or customized image display software.

¹Windows, Visual Basic, ©Microsoft Corporation, Redmond, WA.

²VisionTools, ©Evergreen Technologies, Castine, ME.

Digital Instructor of Chest Radiograph Interpretation for Non-specialists

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I. INTRODUCTION

Frontal chest radiographs are essential gateway to every pulmonary disease. However, the interpretation of frontal chest radiographs is not easy for novices and for clinicians who are neither radiologists nor chest physicians. The weaknesses of their interpretation are as follows: the lack of knowledge about normal roentgenological anatomy of the chest, the lack of anatomic-radiologic correlations, and the lack of perception of silhouette sign and increased density sign among the continuous gray tone of the chest radiograph, especially in the lung field overlapping the mediastinum and the diaphragm. The purpose of this educational system is to enable novices and non-specialists to improve their ability to detect abnormalities in frontal chest radiographs more readily.

II. MATERIALS AND METHODS

The chosen chest radiographs of this system are as follows: 1) Lung cancer, pneumonia and so on, behind the heart and the diaphragm for the study of the increased density sign. 2) Swelling of lymph nodes or inflammation for the study of the silhouette sign of the mediastinal pleural lines, e.g., the paraaortic line, the paratracheal line and the azygosoesophageal recess line. Most of the chest radiographs chosen would look normal to novices but not to radiologists and chest physicians.

The hardware consists of a Macintosh Qadra 800 computer (Apple Computer Inc. Cupertino, CA) with 16 megabytes of random access memory; an internal 1.4-megabyte, 3.5-in. floppy drive; an internal 230-megabyte hard disk, a magneto-optical disk unit NWP559 (Sony Inc. Tokyo, Japan) with 594-megabyte, 5.25-in. disk, and Truvel TZ-3X scanner (Truvel Inc. Los Angeles, CA). Chest radiographs and chest CT data were digitized by a Truvel TZ-3X scanner on the condition of 8-bit, 278 μ m pixel size. The software are Digital Darkroom (Silicon Beach Software, San Diego, CA), Spyglass Transform (Spyglass Inc. Champaign, IL), and SuperCard (Silicon Beach Software, San Diego, CA). Digital images of chest radiographs and chest CT data were processed by Digital Darkroom and Spyglass Transform and displayed by SuperCard on a 13-in. monitor in 256 colors.

III. RESULTS

This system consists of interpretation module and explanation module. First, in the interpretation module, novices can learn weak points of their interpretation. Second, in the explanation module, they can learn interactive case presentations and explanations by hint images and by image processing data.

In the explanation module, when you want to start case studies, you select one image from "Image Index." Then, a frontal chest radiograph of the selected case is displayed on the screen. This corresponds to "Case Presentation" in the flow chart. You can point out an abnormal shadow in the frontal chest radiograph by hand-shaped cursor interactively. That is, if you can identify an abnormal shadow correctly, a "right message" which explains the findings of abnormal shadow will appear on the screen and you will proceed to "Explanation Images." However, if you point out other area except an abnormal shadow, a "wrong message" which tells you that the pointed area is not the abnormal shadow and recommends you to check other areas will appear. And, if you can not detect an abnormal shadow finally, you will proceed to "Hint Images." In the hint images, you can learn fundamental roentgenological anatomy in a chest radiograph of a normal individual step by step. After learning the fundamental anatomy, you can retry to identify an abnormal shadow of the case compared with the chest radiograph of a normal individual. "Explanation Images" are radiographs of lateral view, conventional tomography or computed tomography which explain the abnormal shadow more precisely. Summary contains diagnosis and key findings of frontal chest radiograph of the case. "Review Images" are inversion images, edge detection images, and pseudocolor images of the case. Using edge detection algorithm, you can recognize the silhouette sign as the disappearance of edge line more easily. And presenting different kind of image processing images by turns, you can feedback the features of increased density sign to continuous gray tone in the conventional frontal chest radiographs more easily. After learning "Review Images," you will proceed "Raw Images." "Raw Images" i.e., original digital images which are not processed, are displayed for the final step of feedback to conventional chest radiographs. In "Fundamental Concepts" you can reconfirm the fundamental concepts of findings of the case. These process are one set of data for a case study. At last, you decide whether you continue to study more cases or not.

IV. CONCLUSION

The authors think this system is useful for novices, because they can learn the interpretation of frontal chest radiographs interactively, step by step, and more certainly by using image processing data.

Magnetic Resonance Multimedia Educational Software Tools

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Introduction

The field of magnetic resonance imaging (MRI) is the most costly and technically demanding subspecialty in radiology today. Traditional educational methods, such as lectures and text books, are severely limited in their capacity to maintain and stimulate attention, illustrate three dimensional or time-varying functions, and provide a full range of clinical images related to the phenomenon discussed. Although traditional methods have proven useful for most medical education, they are less effective for radiological learning, which is derived from pictorial subject matter almost exclusively. Over the past five years, the University of Pennsylvania Medical Center radiology department has successfully developed interactive MRI educational software, based on the Macintosh personal computer (PC) platform. By applying recent advances in personal computer technology, these interactive MR educational programs and their associated images have been stored on inexpensive CD-ROM media. The CD-ROM storage medium is both high-capacity and low-cost. Recent advances in multimedia authoring systems now permit radiology educational materials to be played back on either IBM or Macintosh low cost PC platforms. The demonstration will cover radiology-specific issues regarding the selection of multimedia authoring system and large-capacity storage options.

Demonstration

In preparation for the implementation of a radiology educational program, selection of a suitable multimedia authoring system is crucial for the program's success. Radiologic images present specific problems for the program designer. The images must be of exceptionally high quality because radiologists, who will be viewing these images, are sensitive to image quality because their purpose is to distinguish findings and construct diagnoses from the images. MR images are digital by nature and have fairly low image resolution, at 256 or 512 pixels square, as compared to other digital radiographic techniques, at 1024 pixels square. Hence MR images are easily displayed on the personal computer by using commercially available multimedia authoring systems. A second consideration in the selection of an authoring system is textual material. If images are to be presented accompanied by a paragraph or case report description, a simple multimedia application, such as SuperCard®, HyperCard®, Apple Media Tool®, or Director®, would suffice. If a complex series of questions,

student tracking, or hypertext linking is involved, an advanced textual authoring system, such as Authorware® or "electronic book" applications which can perform hyper-linking, would be more desirable. Moving images, such as cardiac cines and dynamic MR contrast tracking sequences, present special considerations. One display option is QuickTime® playback, which is available on either IBM or Macintosh platforms,. This data format was created by Apple Computer and consists of a functional tool set that can be imbedded in the commercial authoring systems by a programmer, alternatively it may be implemented directly into some programs by the end of the year. Development costs can be halved by using a platform-independent authoring system, such as Director®. This system allows for an application to be developed on a Macintosh computer and run on an IBM computer in its original executable format without programming changes.

As a multimedia project progresses, the developer will experience a need for large capacity, inexpensive storage devices. The impetus for this need is for backing up and distributing the large programs, which can often exceed 15 megabytes in size. Large-capacity magnetic storage devices can read and write to removable cartridges, allowing the drive to become infinitely expandable. Traditionally magnetic media has been the most expensive, costing \$1 per megabyte. Magnetic optical media is slightly less expensive and costs 36¢ per megabyte. Write-once and read-many storage options, such as CD-ROM, are significantly less expensive. Recordable CD-ROM is priced at 0.038¢ per megabyte but the initial cost of the drive is on the order of \$3,500. The absolute minimum-cost storage medium to date is a manufactured CD-ROM, priced at 0.003¢ per megabyte. However the requisite number of copies exceeds 200 at that price. Hence write-once CD-ROM is a recent technological development that provides an inexpensive alternative to read-write magnetic media.

Conclusion

Careful assessment should be made on the part of the educational software developer in selecting multimedia authoring tools. Considerations should be made by determining the image quality and resolution, textual content, question formatting, animated sequences, and computers on which the multimedia software will be played back. Large-capacity media selection is also crucial to the success of a radiology educational program. Read-write removable media is cost-effective for backup purposes, recordable CD-ROM technology is suitable for small volume replication, and manufactured CD-ROM technology is most suitable for larger volume replication exceeding 200 copies.

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Personal Computer Based Radiology Teaching Image Data Base

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INTRODUCTION

We will demonstrate our personal computer based system for keeping a radiology teaching image data base. There have been many efforts to design computer based teaching systems for radiology. Often these are written using sophisticated authoring software and although they function well have the disadvantage of being hard for users other than the original authors to add their own case material. We tried to design a system that combines easily available and relatively inexpensive hardware with a simple software package. This will allow many academic departments and individual radiologists to build and maintain a teaching file of high quality images.

HARDWARE REQUIREMENTS

Our system is centered around an IBM compatible personal computer with a 486 DX2/50 processor, 20 MB. of memory, and a 350 MB. hard disk drive (Gateway 2000, Souix City, SD 57049). The image acquisition and display hardware consists of a frame grabber board (PC-Vision-plus, Imaging Technology, Bedford, MA 01730), a monochrome CCD television camera (Pulnix America, Sunnyvale, CA 94086), a high quality television monitor, and an optical disk drive (Pinnacle Micro, Irvine, CA 92718). A camera stand (we had one built in the department) completes the system. The entire setup can be purchased for under 15,000.00. Images are stored at 512 by 480 spatial resolution with 8 bits (256 shades) of contrast resolution. The optical disks hold about 2500 images (256 K bytes each) on each of two sides of a removable disk. The disks are erasable, can be rewritten up to 1 million times, last for 30 years, and are nearly as fast as modern hard disk drives (19 ms. access time and 2 MB/sec data transfer rate). One case's images (up to 9) can be retrieved and displayed in under 2 seconds.

SOFTWARE

The data base portion of the program was written using the Clipper Compiler, Version 5.0 (Computer Associates, Islandia, NY 11788). This uses a standard ".DBF" type data base to store demographic information about each case, the American College of Radiology (ACR) code, textual diagnosis, and a comment. In addition the chief complaint, modalities represented, date of entry, and the contributors initials are stored. Standard database functions such as new case entry, search and list cases on various parameters, edit, and delete cases are implemented.

We have incorporated software released by the ACR into the system to allow generating ACR codes using English language menus for case entry and searching. The program was optimized for speed and a multiple parameter search of our 6700 case teaching file takes less than 2 seconds. This program has been in development and continuous use at the University of Virginia for 6 years to catalogue the radiology department's teaching file.

The image manipulation software was written in Turbo C++ Version 2.0 (Borland International, Scotts Vally, CA 95067). This module provides low level functions to operate the frame grabber board to perform image acquisition, averaging, storage, retrieval and display. To enter images for a case the user is shown the output of the television camera in real time on the image monitor (separate from the computer screen). Once the image is centered and focused it is "grabbed" in 1/30 of a second. The user can then add some annotation text and the image is then stored to the optical disk in less than one second. Up to 9 images are allowed per case. Images can be deleted and added at any time. To obviate any degradation of the images produced by noise in the television signal from the camera an averaging function can be used during acquisition. this takes about 5 seconds and averages the input up to 8 times which cleans up the noise without any loss of image clarity or gray scale resolution.

To display a case one selects it from the text-bases data base using various search strategies (e.g. all renal tumors). While individual cases are displayed the image display routines can be automatically evoked with a single command. The images for the case in question are displayed on the auxiliary monitor in miniature format in less than 2 seconds. Individual images can be selected and are displayed at full resolution in less than .5 seconds. Users can then quickly page through the available images while keeping the text portion of the case record on the computer screen for side by side review.

RESULTS

Using our system one can enter a case with up to nine images in less than 5 minutes. The advantage of the television camera/frame grabber combination is in the great speed with which images can be composed and captured. The speed of display and the quality of images during case review are exceptional. By using a disk caching system (built in to the MS-DOS operating system) the user can switch between up to 9 full resolution images for each case virtually instantaneously. The digital storage of averaged images taken from an industrial quality television camera provides for very high quality results when compared with laser disk technology.

CONCLUSION

Our system for keeping a data base of radiology teaching images is inexpensive (hardware less than 15,000.00, software virtually free from us at less than 75.00). Image quality surpasses that of laser disk technology in the same way that audio CD improves over records or tapes. We tried to make the program work as fast as possible and to have a large storage capacity. The amazing optical disk drives from Pinnacle provide for both these requirements.

Interactive Computer Control of the "Video 3D Atlas of Human Anatomy—"The Lower Extremity" as a Teaching Aid

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Computer assisted instruction (CAI) methods have become quite popular in the medical profession, where the hours available for continuing education are limited (1-3). In Radiology, a specific interest is the "re-learning" of anatomy as new and more detailed imagery becomes available. CAI of anatomical structures allows interactive correlation of anatomical data and medical images. One particular advantage of CAI is the ability to add additional image types and upgrade image quality in instructional programs as techniques develop and improve. A primary goal of this project is to develop a computer based program that will provide the radiologist the opportunity to study the muscles and bones of the knee and their attachments in an interactive fashion, allowing direct comparison of anatomy and imaging in multiple planes.

The instructional program operates on the Macintosh platform and was developed using Aldus SuperCard (Silicon Beach Software) authoring tools. The demonstration set up includes a Macintosh Quadra with a 16 inch monitor, attached to a video disc player with a 12 inch monitor. The video disc player must have an RS-232 serial interface.

Upon initiation, the user is presented with three study choices: a guided tour through all modules, a study module on knee anatomy, and a selection of radiology case presentations. The guided tour presents a general outline of the use and intent of each of the subsequent modules. The tour can be instigated from this main menu or selected parts entered when the user asks for help within another module. The primary window for all study modules (Fig. 1) contains an image display window and a series of buttons which specifically control the module being used. For the case history module illustrated in Figure 1, radiological images are presented in the primary image window. For the anatomy module, the primary image window presents a 3D rendered image of the anatomy. The display of specific cross sectional images can be selected from the 3D rendered image. Text describing the image in the primary image display window is presented in the upper left portion of the primary window. As button options are selected, additional windows are opened to provide the information requested. Quizzes and references follow each of the anatomical cases. The user can choose the type of image(s) to be presented in the quiz: anatomical, 3D or radiological. Any or all can be presented initially or added as the user requires additional information.

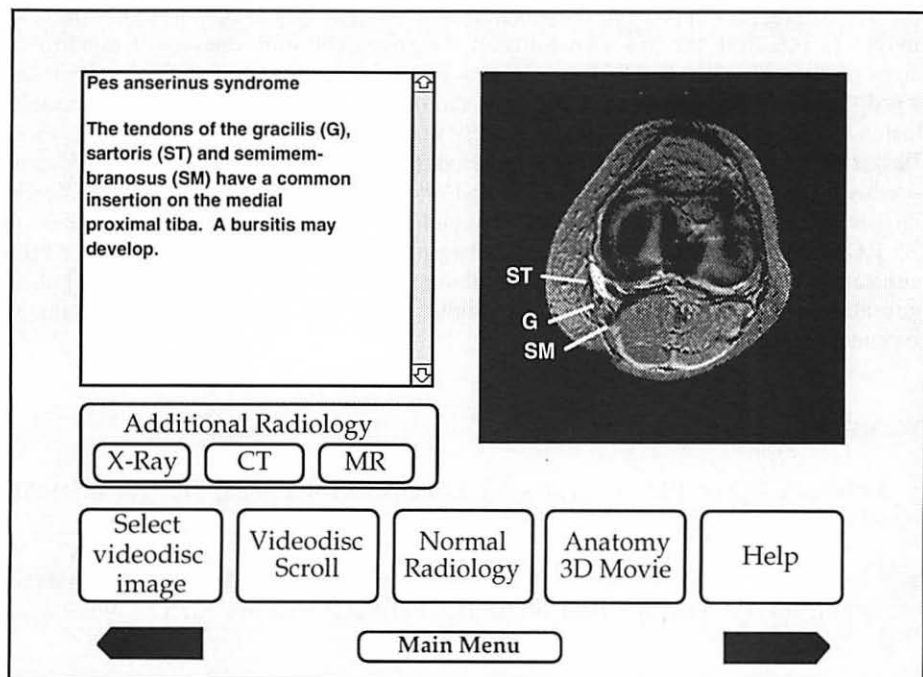


Figure 1. Case history instructional screen

All anatomical images are obtained from the Video 3D Atlas of Human Anatomy, The Lower Extremity (4). This resource is a video disc based reference atlas of cross sectional anatomy obtained from frozen sections of normal cadaver specimens. It includes 187 axial, 190 coronal and 181 sagittal images of the knee joint. The anatomical slices were sectioned in the axial plane at 0.5mm intervals at using a cryomicrotome. Sections were filmed, digitized, registered and computer reformed in the coronal and sagittal planes. Registration and reformatting was performed on a Pixar (Century Computing) computer using native software. These orthogonal images are stored on the video disc along with labeled diagrams and correlated MRI images. Volumetric and surface renderings from radiology studies and from the videodisc anatomy are presented as Quicktime (Apple Inc.) movies edited using Adobe Premier. Segmentation of the anatomical images prior to rendering was done in our lab using IDL (RSI, Boulder, CO) and C programming languages on the Pixar computer. Additional illustrations were done with Aldus Freehand. MRI and CT images are obtained directly, via ethernet, from a GE 1.5T Signa MRI scanner, GE High Speed CT scanner or GE High Light CT scanner. All these images are windowed using IDL for the Macintosh and stored as Macintosh PICT files. Text files are developed using any word processor and are stored as ASCII text files.

Using this approach, we were able to successfully incorporate a variety of images to illustrate the gross anatomy of the knee. The high density of anatomical slices on the videodisc and their availability in all three orthogonal planes provides an appropriate reference image for common radiology planes. Because of the modular design, radiological material can be readily updated by replacing the existing image files or by adding new ones and incorporated them as choices on the supercard menu screens. Text files can also be altered and/or tailored for the level of the audience. Further enhancements of the program may include migration of the image database to CD ROM. The CD ROM technology is beginning to support the data transfer rates required to present full motion video available from the video disc, and would allow presentation of the anatomical images in higher than video resolution directly onto the computer screen.

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An Automated System to Monitor Imaging Equipment Service and Billing Information

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In the Russell H. Morgan Department of Radiology and Radiological Science at the Johns Hopkins Hospital we have been using a computer based system to track equipment service information since 1986. Between 1986 and 1992 the information available for monitoring outside service led to a savings of over \$750,000.

During this time three things occurred that changed our needs for detailed equipment service information. First, the size of our department has more than doubled. We now have over one hundred x-ray tubes, five MR scanners, six CT scanners, more than twenty ultrasound scanners and over 40 radiographic film processors. Second, state and federal regulatory bodies, as well as the JCAHO, are requiring more and more information about maintenance and QA testing of the equipment. Third and most important from a financial point of view, we are now utilizing a third party payer to reduce our maintenance cost. Like any other insurance organization, they require thorough documentation before paying the invoices from service vendors.

In this same period we identified weaknesses that made the initial computer based system difficult to use. Although we could use the system on our network, we had to be very careful about who could do what and where. On more than one occasion the system appeared to delete all of the data from the monthly data file. Fortunately we found ways to recover all of the information.

Furthermore, if we input data from more than one network workstation there was a good chance that one service request entry

would overwrite another.

There was no way to modify the system. We were unable to change the list that held the information about the companies we dealt with or the list that held information about our service technicians and we had trouble adding new capabilities to the system.

If we had a work order that one of our technicians repounded to and later found the he would need vendor assistance, we had to generate a separate work order to account for that assistance. The structure of the data file was such that it could only handle inside or outside service information, not both. This meant that in some cases we had to keep track of two work orders for one problem

These observations led to the development of a new system that overcame the weaknesses and added many new features. Development of the new system started in 1988 and is ongoing. The new system which was installed May 1, 1993 uses a standardized file format common to more than one commercially available package, and lends itself nicely to data manipulation and extraction by those packages or programs written in the C programming language, or Prolog.

The new system is written to operate in a network environment, and allows information to be entered and viewed from anywhere in our department without the danger of data collisions. It also allows the area supervisors to track the status of equipment service being performed in their areas. This lessens the work load for the Physics and Engineering staff. The work orders are initiated in the section where the equipment failure occurred, and are printed at that location instead of being delivered by Physics and Engineering personnel.

At this time we are adding new functions to the system. These include an extension to handle x-ray equipment QA and radiographic file processor QA information. After that we intend to add the ability to contact staff via our pagers automatically when a new work order is initiated.

RADPATH: An Update of Computer Aided Radiologic-Pathologic Correlation Software

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RADPATH is a Macintosh based teaching environment which utilizes diagnostic images combined with pathologic correlation and textual information to enhance learning of the clinical and imaging features of disease processes.

A Macintosh computer based program created with Macromind Director, RADPATH uses a case study tutorial approach to guide the user through textual and visual information of disease processes in a user-friendly environment. Mediastinal masses and parotid masses will serve as the pilot topics for demonstration.

The viewing of pathologic gross and microscopic specimens offers actual correlation and potential explanation for image characteristics and patterns generated by multimodality diagnostic imaging devices. The user-friendly interactive format of RADPATH demonstrates the effectiveness of computer based instruction, providing the user with easy access to an integrated resource of text with diagnostic and pathologic images of mediastinal and parotid masses.

RADPATH offers the opportunity for rapid and comprehensive understanding of medical disease processes by integrating diagnostic and pathologic images in a computer based teaching environment.

DICOM 3.0 Implementation Tutorial

An Interactive Windows 3.1 Program

Robert Hindel

R H Consulting, Orange, CT

The network implementation of DICOM 3.0 according to part 8.0 of the standard requires generation of Protocol Data Units (PDUs). There are essentially two groups :

PDUs which are related to the network association and
PDUs which contain commands and information objects

The first group requests establishment of an association, acknowledges such an association, rejects establishment for various listed reasons, releases association, reports such a release or aborts an association.

The other group (type 4) carries the message, which is subdivided into commands and information objects with associated attributes. Depending on the application which is defined by SOPs (Service Class-Object Pairs) this content of the message will vary.

The demonstration software illustrates content and coding of various PDUs. Within PDUs there are information elements which are predefined for a global network or system as, for instance, Unique Identifiers (UIDs). Other information elements are case dependent, but can be transferred from other sources such as a RIS or HIS. Still others are case dependent but must be entered at the time of the encounter, for instance, time and date of an examination, name of the reporting radiologists etc. Still other information elements can be put into templates for specific sites such as CT, MR or other modalities. The program highlights such categories of information elements.

Coding is illustrated for typical applications such as reporting or archiving images. The coding instructions of the DICOM standard are listed in part 5 and are based on the ISO documents 8859, 646 and others. Generally the coding pattern of earlier versions of the standard (ACR-NEMA Standard 1.0 and 2.0) is retained : the "Tag" of DICOM 3.0 is composed of the

group number and the element number of version 2.0. The Tag is followed by a value length indicator and by the coded value entry. Part 5 of the standard contains detailed instructions for encoding date, time, UIDs text strings and binary strings, etc. For encoding binary values the Transfer Syntax specifies either "Little Endian" or "Big Endian". The distinction is that "Little Endian" encoding orders the bytes of a composite binary number with the least significant first and the most significant last, while "Big Endian" encoding reverses the ordering sequence.

Pull-down-lists illustrate enumerated values as, for instance, data types commands, message control headers etc. Operators of the program can transfer listed choices into the table of information objects or type in new values.

Progress In Healthcare Informatics: Challenges of Telematics

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1. Healthcare the information age

In recent year's information processing systems and software architecture's rely more and more on message exchange between different processes.

This evolution is driven by two main factors:

- *The growing need for information and information exchange.*

In view of this there is a need for reliable and efficient message exchange mechanisms, which offer a consistent interface to user.

- *Growing user requirements.*

Growing user requirements has lead to an explosive growth in complexity, as a result of which an information processing task can no longer be carried out by a monolithic system, each carrying out a specific task but by distributed system eventually across a network.

Several advanced computerised patient record systems have been successfully installed in hospitals and ambulatory care settings but few have been widely replicated and no common architecture is agreed until now. There are, several studies that show the electronic patient records can lead to better quality and more efficient patient care management (e.g., fewer lab tests, shorter lengths of stay).

It is essential that a new application of technology either improves the quality of health care, increases the efficiency of providing care, or decrease cost. The high performance information highway should take this and other issue like standardisation into an accepted common framework. Several initiatives of the CEU¹ are contribution to this framework. Advanced Informatics in Medicine (AIM), Standardisation initiatives CEN 251 / 4 Medical Imaging and Multi-Media, TEN-IBC (Trans European Networks - Integrated Broadband Communication) and other actions are driving towards a common concept.

2. Medical Informatics - Telematics

Medical Informatics is a well know domain applying informatics tools towards the automatisation of the medical processes. Recently we start getting more focused towards telematics, a combination of informatics and telecommunication. More efforts should be made towards the user community including all actors, making them aware of this shift and of the impact these medical telematics infrastructures can have in the health-care world. This going from equal medicine, towards cost reduction and more advanced technologies. The new research programs, projects and standardisation activities need to be synchronised with this approach.

3. The Brussels Initiative

The objective for the MID-SIM² non-profit company is to develop regional information infrastructure in health-care with the Brussels region as pilot area. This is one of the first examples of the creation of a health care infostructure.

This infostructure includes as well the telematics infrastructure as the related standards and other components in order to create an infrastructure which is open to additional participants. This creates an intermediate organisation in between the users of the medical services

¹Commission of the European Union.

²Medische Informatie Dienst - Service d'Information Medical (Healthcare Telematics Institute)

(medical actors and individuals) the suppliers of medical services and the suppliers of telecommunication networks and services (operators) (Fig 1.).

A partnership structure is imbedded with a balanced representation of the medical sector, the telematics sector and the government (economy and health-care). The participation of the medical sector which after all the key user (next to the individual citizen in the context of prevention programmes or home care policies) is considered as being of prime importance for all other parties involved. The open structure of the interdisciplinary co-operation model of MID-SIM allows in a flexible way further extension with additional expertise as well at the national or at the regional level.

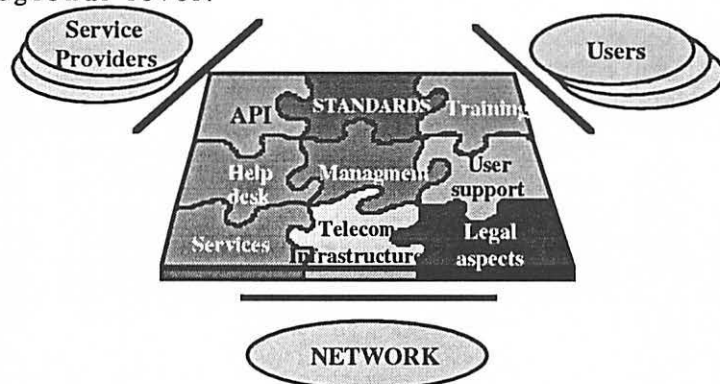


Figure 1.
Expertise and integration domain MID-SIM V.Z.W.
The Health care infostructure

The MID-SIM project is an initiative of Horizon-21 Medical Services N.V. with the assistance of Technopol VZW. Technopol's mission is to stimulate economic development in the Brussels region. Two of the four policy lines of Technopol are the development of the potential on health-care know-how and the development of an advanced telecommunication infrastructure. The MID-SIM project is as such supporting both policies. In addition the MID-SIM project has been proposed and accepted as a pilot project for the research projects which are preparing the fourth framework programme of the European Union with respect to the usage of telematics services in health-care. It does fit in this context

in the strategic guideline described by the CEU in the "White Book" of Delors "Growth, Competitiveness, Employment, the challenges and the way forward into the 21 St. Century".

3.1 Services and infrastructure

The MID-SIM concept covers the total portfolio of telematics services within the medical sector : access to information services (data, text, images,...), telecommunication services (electronic mail, structured messages, interactive video communication, ...) The objective of MID-SIM is to implement as well the required infrastructure as the supporting organisation. This includes the telecommunication infrastructure but also the education, support and administration, promotion, standardisation and legislation.

3.2. Definition of an interdisciplinary organisation model

Definition of a consensus model between the medical sector, the public sector, the government and the telematics sector. This covers primarily the set-up of national co-ordination body for the development and implementation of pilot projects with following objectives :

- synchronisation of the various actors within the medical sector with respect to the introduction of telematics services within the sector on all levels (home-care, first, second and third level) and for all actors.
- act a forum in discussions with medical sector policy makers, public sector and social security with respect to:
 - synchronisation of legislation and procedures on the usage of telematics services in health-care
- definition of the impact of the use of telematics on the medical actions and the possible consequences for tarification (e.g. payment of second expert involvement)
- definition of policy towards ethical and privacy issues of the use of telematics in health-care.
- synchronisation and negotiation with the Telecom sector with respect to the validation of the technical architecture and related standards.
- ongoing synchronisation with the European and international activities in this field
- set-up of educational services for different actors involved.
- to support a policy of quality improvement and where possible also a more cost-effective application of telematics in health-care.

4. The Roadmap for Standardization in Medical Imaging: An international approach

The standardisation work related towards medical imaging and multi-media is influenced by several strategies (Table I). Several steps are defined for the evolution and integration of medical imaging standardisation, where the WG4 is mainly performing an integration task. (Fig 2).

Integration of DICOM V3.0 into the CEN TC 251 strategy for the European Standardisation of Medical Imaging Communication. Inter-relation goals are to:

- Establish joint ownership of DICOM with ACR-NEMA by Mid 1994.
- Revise the MEDICOM Architecture document to incorporate DICOM V3.0.

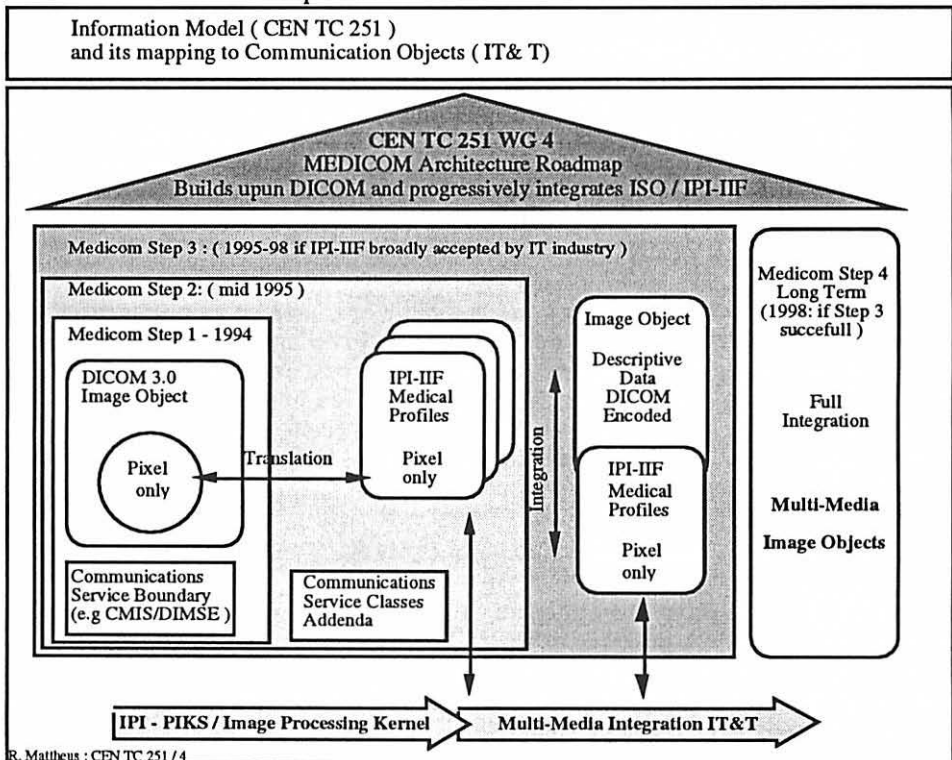


Figure 2.
The Roadmap for Standardization in Medical Imaging:
An international approach.

A next step is develop jointly with EWOS EG MED and ACR-NEMA one or more Medical Profiles of IPI-IIF which support the image pixel and directly related pixel attributes defined by by ISO / IPI-IIF.

- Fit into the CEN TC 251 Model and objects
- Fit the European requirements
- Look towards the standardisation from the application domain point of view which results in the use of more IT&T standards. More efforts should be used to ensure that this approach will also be used on international bases.
- One Standard

Table I: CEN TC 251 /4 Strategy

5. Multi-Media - Electronic Medical Record

The electronic medical record is the compilation of individual patient data that needs an agreed syntax, semantics, format and transmission protocols to make certain that the receiver of the information understands the message in the same way it was meant by the sender. The medical record consists out of different data-types: going from written documents and data, towards images, video and signals; typical multi-media information.

It is in the interest of the users all over Europe, as well as in USA and Japan, to move forward and create more commonly shared and more universal content and context for the records in order to bring the existing elements in conformity with future needs for the international medical community. A glue, integrating the different components is needed in short time.

6. Integrated Broadband Communication

Advances in communications have been one of the major driving forces of socio-economic progress in recent years. Electronic communications offers also the potential for addressing the challenges in society of environment and geographic disadvantages.

The next-generation communications protocol must provide sufficient gains to justify the tremendous cost

required to evolve the communications infrastructure. It must be capable of handling multimedia communications between users, between users and machines, and between machines. In the quest for a next-generation protocol to provide broadband ISDN (B-ISDN), the standards bodies considered many options: fast circuit, burst, synchronous transfer mode, and asynchronous transfer mode (ATM). The promise of ATM has created the first situation in the high-tech industry where all players are backing the same networking protocol.

Recent publications identifies some of the huge changes in cost that are likely to occur in communications over the next decade. It provides information about how investments by corporations and public institutions, such as hospital centres, are taking advantage of new, broadband technologies. It is clear from these new uses that the greatest economic benefits from future communications will come from investments in high-bandwidth infrastructure, particularly since it offers much greater benefits to users. While this essay has not addressed the issue of prices for these new services, the dramatic decline in prices illustrated by previous research that is reviewed here suggests that pricing for higher bandwidth services will not be much more expensive than narrowband services by the late 1990s.

7. The European efforts

The European sponsored (CEC /AIM) project European Integrated PACS (EurIPACS) is playing an important role in this work. A Picture Archiving and Communication System, supported by a multi-media medical image database, will be integrated with all other components of a Hospital Information System (HIS), resulting in a second generation distributed PACS architecture test bed in 95.

A focus is given towards "Integrated".

- *Integrated in a hospital environment stressing the need for having clinical useful systems.*
- *Integrated with the other information systems; the departmental systems.*
- *Integrated by means of standards and coordination with CEN TC 251.*

The EurIPACS project can be seen as an infrastructure which will give us certain functionality, which you can

extend when needed. Basic functionality like image management, storage and archiving are implemented. Other projects like Computer Vision in Radiology (COVIRA), Software for Multimodality Images and Education (SAMMIE) and Multi-Media Interaction with Radiology Data-Bases (MILORD) are key projects in the imaging line. High performance Information Infrastructure in Medicine (HIM) an other CEC project for the definition of trail specifications regarding health care for Trans European Networks using Integrated Broadband Communication started in Dec 93. The European Standardization institute CEN TC 251 "Medical Informatics" has besides several other action points, focused on interoperability and messaging in the imaging and multi-media, and is close working with ANSI on several issues.

Summary

Doctors who want to make the most of computers to treat patients are being thwarted by systems that can't communicate with each other. More efficient management and processing of the information, allowing efficient sharing of information across the health-care environment, needs a common information infrastructure. Several components of this infostructure can be worked on, on international basis.

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ADDENDUM

Papers not received in time for publication

SESSION 4

Application of a Microcomputer-Based Diagnosis System Improves Diagnostic Accuracy and Reduces Costs of Dynamic MR Mammography

H.B. Bieling, C.K. Kuhl, A. Steudel, University of Bonn, Bonn, Germany

SESSION 9.

Speech Recognition for Radiologic Reports: An 18 Month Clinical Experience

Harold N. Walgren, Luke Air Force Base, AZ

SESSION 15

Legal Aspects of Digital Image Management and Communication

Caroline Laske, Free University of Brussels, Brussels, Belgium

SESSION 19

Evaluation of a Dedicated Ultrasound PACS System

*G. Donald Frey, Anthony J. Wagner, Rick E. Olinger, Christopher J. Starr
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Legal Aspects of Digital Image Management and Communication*

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THE LEGAL DEBATE

Digital diagnostic image management and communication raises a number of legal questions, from data protection issues, security and integrity considerations to the debate about the legal status of digital documents. We are thus dealing with a very wide range of legal doctrine and arguments. The methodology adopted in this study was first to identify those areas of activities in digital image management and communication which raise some legal considerations. Subsequently, the existing law was examined for answers and guidance in relation to these previously identified legal questions. This resulted in two possible situations: either the existing law addresses the issue in question, or the law is silent on that point which effectively means a legal vacuum that needs to be dealt with. In the latter case it is useful to draw analogies with other sectors which deal with digital data and documents (eg. EDI), so as to seek guidance on how to resolve any legal problems.

Several functions are embedded in image management and communication systems (IMACS). In a typical scenario personal medical data is collected from the Radiological Information System (RIS), possibly also from the Hospital Information System (HIS), and matched with the images acquired through the appropriate modality. The medical specialist views and processes the images and makes a selection which, accompanied by the radiological report, becomes a part of the patient file which is usually stored in the short term storage and later transferred to a long-term archive. In addition to this basic scenario there is the possibility of transmitting the images to another location, including outside the hospital (although this may already have happened during the process described above). Furthermore, images may be subject to a wide variety of 'manipulations' at any stage before long term archiving.

The underlying legal problem is the intangibility of digital data. Electronically generated data may be altered or destroyed without trace as though it has never existed. In other words, digital data is inherently volatile and can thus be considered as unreliable. From a legal point of view there are a series of misgivings as to the data's legal acceptability. These may be pre-empted by creating a legal framework that recognises this sort of data. Fundamental to such a framework are a series of definitions of some of the basic concepts in digital imaging, as well as mandatory procedures which create data security as well as transparency on any steps taken in IMACS.

THE ISSUES

Let us consider some of the legal concepts at issue in digital image management and communication :

1. Data Protection

To the extent that personal medical data is collected, processed and stored the rules of *data protection legislations* and practices must be observed so as to safeguard the *patient's privacy* and *guarantee medical confidentiality* to which all medical professionals are bound through a series of legal and quasi legal provisions.

In the data protection legislations of most European Union Member states medical data is classed as particularly sensitive data and therefore needs to be protected through appropriate safeguards [1]. In the digital imaging environment this is particularly important since, for effective use, IMACS need to be integrated with other information systems such as HIS and RIS. The information generated by the totality of these systems offers a very complete profile of any patient. Thus, the danger that the patient's right to privacy and medical confidentiality may be jeopardised is potentially very high if appropriate data protection measures are not adopted. There is thus the need to adopt a dynamic data protection and security policy which is specific to the digital imaging environment, identifying potential threats and harms to data protection and medical confidentiality and formulating appropriate remedies.

1.1. Data Protection Principles:

The basic data protection principles stipulate that data may only be:

- obtained and processed fairly and lawfully;
- stored for specific and legitimate purposes and not used in a way incompatible with those purposes;
- adequate, relevant and not excessive in relation to the purposes for which they are stored;
- accurate and, where necessary, kept up to date;
- preserved in a form which permits identification of the data subjects for no longer than is required for the purposes for which those data are stored [2].

1.2. Security:

Furthermore, appropriate security measures must be taken so as to protect the data from accidental or unauthorised destruction or accidental loss as well as against unauthorised access, alteration or dissemination [3]. Security measures must be of such a nature as to allow for maximum protection of the data without obstructing the necessary availability of the data for effective and efficient health care. Furthermore, when devising such measures a balance must be observed between legal (regulatory) and technical solutions, customs and practices.

In digital imaging the security requirement is relevant on several levels:

1.2.1. Overall system security with appropriate back-ups and fail-safe mechanisms must safeguard the integrity of the data against destruction, alteration or loss due to a system failure or at least minimise the effects of such a failure. This is particularly important in view of the integration of multiple modality and systems (ie. a bug in the modality may infiltrate and cause damage in IMCS). Furthermore, automatic log-files

protocolling any alterations to the data, provides a certain transparency which helps to establish data accuracy and completeness and thus ensures its quality.

1.2.2. *Access security* is essential, in particular if there is to be potential access integration between IMACS and other systems such as HIS. The right of access is a right to use data for different purposes, such as to read, edit, add, communicate, copy or delete data and files. Thus, the right of access is not a blanket right. Instead it must be selective, defined in detail and according to differing authorisation levels. With the aim of obtaining maximum access security each access right should be:

- linked to the person seeking access and to his/her function,
- limited as to the purpose for which the data is used,
- limited in time.

1.2.3. Security is an essential element in *transmission and communication*. Data must be safeguarded, on the one hand, against wilful or accidental interception which would jeopardise the patient's privacy and potentially the integrity of the data.

Encryption is a possible solution whereby it would be sufficient to encrypt the data which links a set of images to a particular person, such as identifiers in form of name or identification numbers. Encryption of the actual image is likely to be unnecessary, unless data subject related comments are included on the actual image. On the other hand, and related to the first point, is the matter of safeguarding the integrity of the data whether it may be subject to alteration or destruction due to a technical failure or following interception or interference. In view of the intangible nature of electronically generated data, it is essential that every image has been authenticated (eg. digital signature) which would subsequently allow for the detection of any alteration to the image. In this way there is evidence of the actual image sent and received which may be vital when trying to establish liability in cases of diagnosis made from a distance.

1.3. Data Subject:

Data protection law usually provides the data subject with a number of rights such as the knowledge of the existence of the automated file, its purpose, its content, the identity of its controller, as well as a right to rectification and erasure of data which may have been processed contrary to the basic data protection principles as laid down in domestic and international legislation [4]. The health care sector is often considered as an exception to the duty of disclosure to the data subject. The medical specialist is given a discretion how much to disclose to the patient. As far as the right to erasure and rectification is concerned we may be faced in digital imaging with the impossibility to comply, since in the case of most long-term archives it is impossible to single out certain elements of a patient file and erase or alter them.

1.4. Transborder Data Flows:

As far as personal data crossing national borders is concerned, this may only be prohibited on data protection grounds if the importing country does not have equivalent data protection measures to the state exporting the data [5]. In the European Union two Member states still lack data protection law, namely Greece and Italy. Transmission of personal data, including identifiable images may thus not be undertaken with either of these states.

2. Legal Recognition of Digital Images

Considerable uncertainty surrounds the legal recognition of digital images and digital files in general.

As outlined above the intangible and thus volatile nature of the electronically generated data means that such data is inherently unreliable. This is problematic from a legal point of view and it is thus essential to render such data legally acceptable which can be achieved through two means.

2.1. Reliability:

The data in question must be generated in the most secure and reliable circumstances. Thus data protection and security measures are also relevant for making a system and its data reliable by creating maximum security and transparency. In other words, the more secure and reliable a system generating electronic data can be considered, the more acceptable its data will be for legal purposes.

2.2. Legal Relevance:

Legal recognition of electronic data requires definitions relating to the moment of when an image becomes legally relevant. These definitions are to form the basis of an appropriate legal framework. In the digital imaging environment there is the need to define what an image is, when it comes into existence and when it becomes legally relevant. It can be argued that technically an image comes into existence when its header is defined. This image may, however, become legally relevant at some other point, depending on the legal concept that is involved.

2.2.1. First of all, in *data protection* terms [6], an image is 'personal data' as soon as it can be related to identified and identifiable data subjects. Thus, for data protection purposes an image becomes legally relevant once personal patient data is included in the header, and from that moment the image is subject to the applicable national and international data protection principles and rules.

2.2.2. For the purposes of the patient file as a *legal document* the images become legally relevant once they have been used for diagnosis and validated by the medical specialist. Thus these images constitute the basis for the established diagnosis, and since they become an integral part of the patient file (also in legal terms) they may no longer be altered irreversibly.

2.2.3. Digital images may further be legally relevant as *evidence* in a court of law in the course of litigation. But today it can still be said that there is considerable uncertainty as to the admissibility of digital files as evidence in court and as to the evidential weight such evidence may represent.

2.2.4. Lastly, digital images may be legally required as part of specific *procedures* of organisations such as social security or health care administrations who may, for example, require paper documents or handsign reports as part of their eligibility procedure. In other words, the 'form' (ie. the digital form) of such images is not recognised as answering the legal requirements of some specific procedures.

CONCLUSIONS

We have seen that digital images may be legally relevant in different types of situations, but since the law does not specifically address and recognise digital images, there is considerable uncertainty as to whether such images will be legally valid and whether they will be given the necessary and appropriate legal and evidential weight. It is essential that this legal vacuum should be filled since it potentially undermines the entire use of digital images.

Furthermore, the discussion above has shown that appropriate data protection measures need to be taken, not only to comply with existing legislation but also so that digital data may be generated in highly secure and reliable environments. The more reliable the data, the more ready the judiciary to recognise it for legal purposes.

It has become obvious from this brief outline that the legal perspective of IMACS is one that must not be neglected. Although there has been as yet no major litigation on the matter, it is essential to address and resolve these issues as soon as possible. Any technological progress must be accompanied by the appropriate legal considerations. The lawyer's role in this matter is not to hamper scientific advance by having to impose normative rules retroactively, but rather to accompany it and facilitate its realisation.

NOTES

- [1] See Article 6 of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*, on which most European data protection legislations are modelled;
- [2] See Article 5 of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*
- [3] See Article 7 of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*
- [4] See Article 8 of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*
- [5] See Article 12 of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*
- [6] See the definition of personal data in Article 2a of the *Council of Europe Convention N°108 for the Protection of Individuals with Regard to Automatic Processing of Personal Data*

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